It is familiar to those who have performed Millikan's oil drop experiment. For the balloon of radius 30 cm, F is the gravitational attraction, mg. Now, m is, lets say 10 gm, so mg = 10 x 981 dynes = 6π x 0.1 x 30 x v
(.01kg.) (.9 N)

giving $v = 1.735$ m/sec.

The balloon certainly does not fall at a rate of 17 m/sec. The critical velocity is given by $Vc = \frac{Kn}{\rho a}$ where K, the Reynolds number is about 1000, η, the viscosity of air is 182μ poises ρ, the density of the medium (air) is .0012 gm/cc so

$$Vc = 15 \text{ cm/sec}$$

The flow will be turbulent above this velocity, which is quite low. Only for very tiny spheres will the flow be streamline, unless very low speeds are used. However, try dropping a marble, radius .8 cm, mass 5 gm, in a cup of glycerine (viscosity about 4000 centipoises at 10°C). The density of glycerine is 1.26. (Syrup will also work, if sufficiently concentrated).

$$Vc = \frac{1000 \times (4000 \times .01)}{1.26 \times .8}$$

$$= 39 \times 10^4 \text{cm/sec}$$

whereas $6\pi(4000 \times .01) \times .8 \times v = 5 \times 981$

The terminal velocity of the marble through the glycerine is only 8 cm/sec. So this is a very easy way to measure the viscosity of viscous liquids--simply drop a marble in and find how long it takes to reach the bottom. For less viscous liquids such as water, we must employ a very low velocity, to ensure streamline flow occurs.

One way of doing this is shown in the fig. A hole is poked at X in a styrofoam cup with a pencil point, so that a straw can be pushed through, making a tight fit. The end of the straw rests on the top of a second cup which has had only about 1/2 cm torn from the lip. Water is poured constantly overflowing the first cup until the second is filled. The flow, being slow, is now streamlined, and it will be found it takes much longer to fill the second cup with cold than hot water, because of its lower viscosity. However, the head of water must not exceed 1 cm.

The quantitative aspects of this experiment show (Poiseuille's formula) that the quantity of liquid Q flowing per second through a tube of radius a and length ℓ (2 mm and 20 cm for a straw propelled by a pressure p) is given by

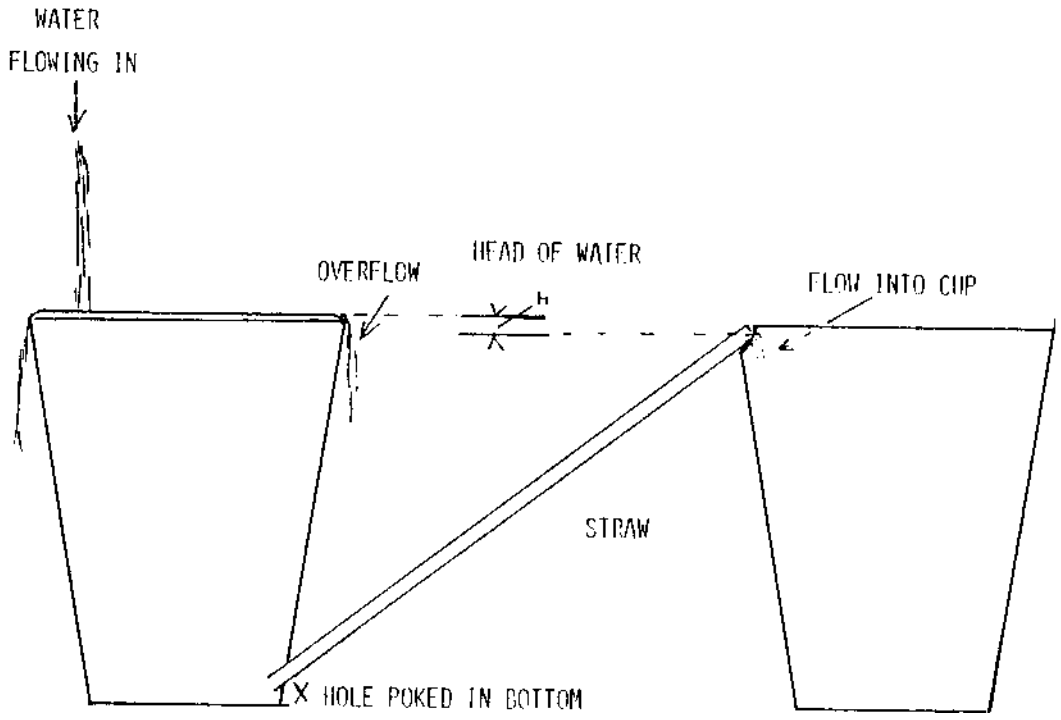
$$Q = \frac{\pi P a^4}{8\ell\eta}$$

If the height differential is h, $p = \rho gh = 1 \times 981 \times h$. The volume of the cup is 6 oz or 203 cc, so if $h \sim .5$ cm and $\eta = .01$

$$Q = \frac{\pi \times 1 \times 981 \times .5 \times (.2)^4}{8 \times 20 \times .01} = 1.5 \text{ cc/sec}$$

so it should take 132 sec (about 2 minutes) to fill the cup, which it does.

The dramatic difference in flow time filling the cup with hot or cold water arises because of the large temperature dependence of viscosity which is even more noticeable for the glycerine. This presents a severe problem with automobiles, since the cold oil does not flow and lubricate on starting the engine. This has lead to the development of motor oils whose viscosity remains relatively constant with temperature. It is interesting to measure the viscosity of different motor oils as a function of temperature, using the technique above, but qualitatively the difference may easily be seen as one pours oil into one's car from the can in mid winter and summer.

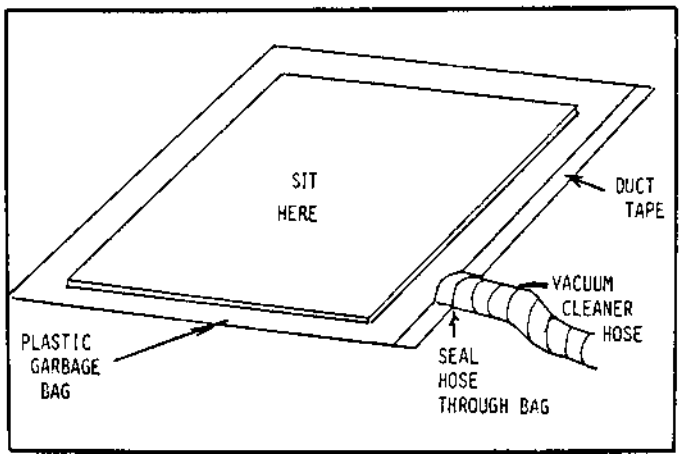


Experiment 3.15 Effects of pressure

Materials: garbage bag, vacuum cleaner which blows

Method: This experiment was suggested by Rae Carpenter and Dick Minnix, and is outside our other experiments because it required more equipment--which is, nevertheless, simple and fun. It requires a vacuum cleaner with an outlet that can blow rather than suck. You take a plastic garbage bag and tape the top end with duct tape so that it is air tight, except for the vacuum hose, which is sealed poking into the bag through the opening, as shown. Put a piece of thin plywood on the bag, then sit someone on the bag, and turn on the cleaner, (Fig. 1). The bag blows up, lifting quite a heavy individual--and tipping him over unless he is steadied! If the board is, say 50 cm by 50 cm (2500 cm^2, 387 $in.^2$) and if the individual weighs 75 kg (165 pounds) the pressure is 2940 pascals (4.26 pounds/sq. in.) which even a relatively inefficient vacuum cleaner can supply.

A variation of this is to seal the garbage bag completely with tape, then poke eight to ten straws in along the edges (they may need sealing to the bag).Eight or ten people blow through the straws, and can easily lift anyone sitting on the bag.

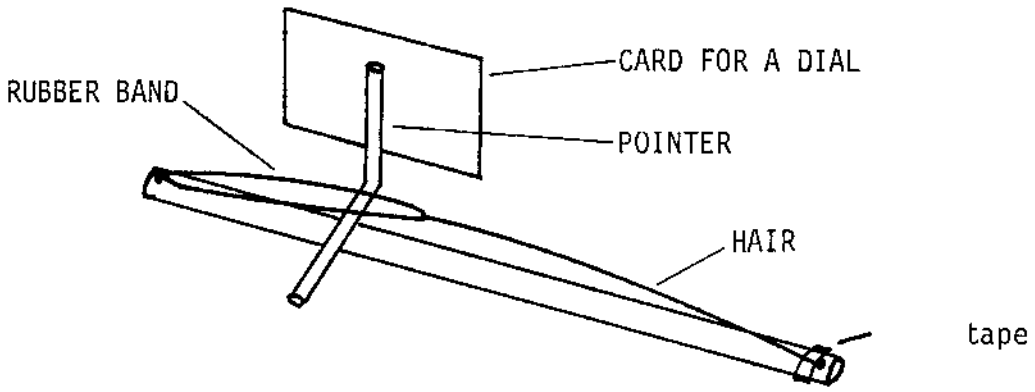


Experiment 4.01 The hygrometer

Materials: straws, card, rubber band, tape, hair.

Instructions :-

Attach a long hair (blonde works best!) to one end of the straw, and keep it taut with a rubber band on the other end.



On moist days, hair absorbs water vapor and becomes longer, rotating the pointer. On dry days it shrinks. You can calibrate the hygrometer by listening to the radio or television to find the value for the humidity.

Experiment 4.02 Thermal Expansion of a Soda Straw

Experiments on heat requiring only very simple equipment are difficult to find. This experiment on expansion requires only three plastic drinking straws, sticky tape, very hot water, a pencil, a piece of card (or paper) and a Styrofoam cup. Bind two straws together very tightly along their length with sticky tape, as shown in Fig. 1. Fasten the top end to a sheet of card or paper using tape. Mark the position of the bottom end very carefully. Now, you must use the cup to pour the hottest water available through the lower straw. To do so, make a little funnel by folding one end of the third straw, as shown in the figure, so that it will fit into the top end of the lower straw. Slice the top end off the third straw diagonally to make it easier to pour through. Record how much the lower end of the straw shifts by making a pencil mark. Qualitatively, it is easy to see how the hot straw expands against the cold one, as shown in Fig. 2, pushing both straws into a bow shape.

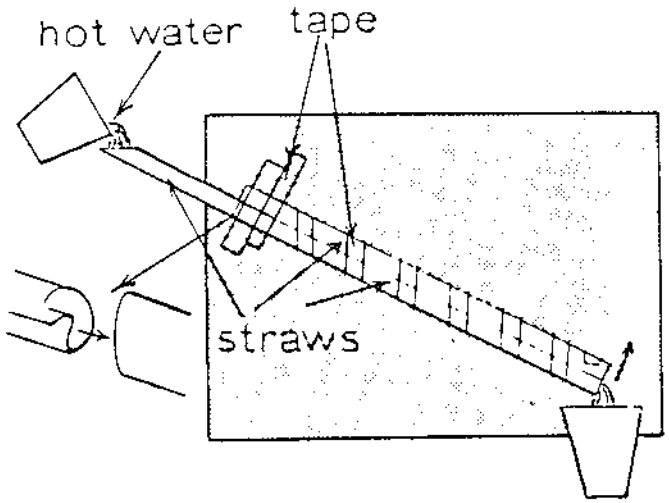


Fig. 1

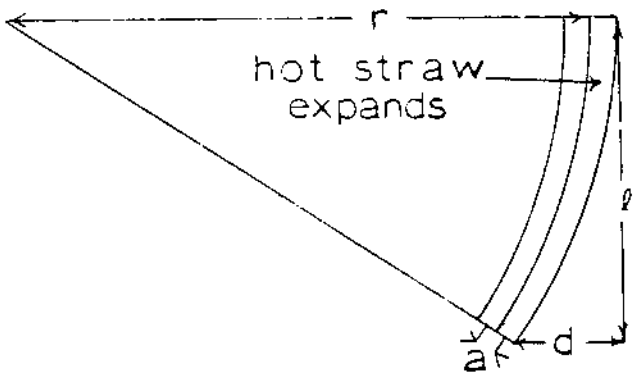


Fig. 2

It is also interesting to study the result quantitatively. Boiling water will be at 100°C but if it is not available, measure the temperature using a thermometer (we shall show in a later issue how to make a thermometer out of a soda straw). Measure the length of the straw ℓ, and the distance it moves, d. Then, the radius to which the straws bow, r, is given by $2rd = \ell^2$. If the center of the straws is separated by a distance a, and the hot straw expands an amount x, then

$$x = (r + a)\,\theta - r\,\theta$$

where $\theta = \ell/r$

$$x = a\ell/r = 2\,ad/\ell$$

The coefficient of linear expansion α is given by the ratio

$$\alpha = \text{expansion/original length x increase in temperature}$$

$$= x/(\ell t)$$

where t is the temperature increase.

Hence,

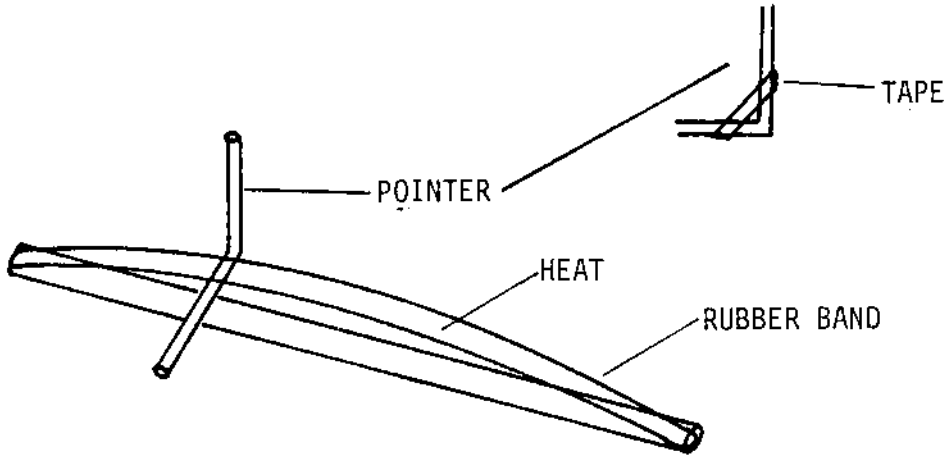
$$d = 1/2\ \alpha \ell^2\ t/a$$

The coefficient is roughly 10^{-4}/°C for the type of plastic of which straws are made, so a temperature rise of 50°C where a is 0.5 cm and ℓ is 20 cm moves the bottom end of the straw 2 cm which is easily measurable. Heat loss and other problems generally give rise to a low measured value for the coefficient.

Experiment 4.03 The effect of heat on a rubber band

Materials : - Rubber band, two straws, match

Instructions: -



Stretch the rubber band over the ends of the straw (cut the straw to a suitable length and notch the ends if necessary. Bend about one inch at right angles for the second straw, to act as a pointer. Tape it to stay in that position. Place the pointer under the band. Heat one side of the band, and notice from the pointer that side contracts. Breathing on it may provide enough heat - if not, use a match.

Qualitative: - Most materials expand on heating - however the molecular structure of rubber is such that it contracts on heating, or rather, its elasticity decreases.

Experiment 4.04 Heat and Work

Materials: - one rubber band (reasonably large)

Instructions: - Place the rubber band between two fingers as shown, stretch it, and place it against the upper lip. It will be felt to be distinctly warm.

Hold it away from the face in this stretched position for a few seconds, release the tension and again place against the upper lip. It will be felt to be distinctly cooler than the surroundings.

Qualitative: - In stretching the rubber band, work was done on the rubber band. Part of this work went to heating the rubber band. On relaxing, the rubber band did work on the fingers, and drew on its heat energy to provide the work required. In the same way a gas, when compressed, rise in temperature, and cools on expansion against a piston.

Quantitative: -

This is an experiment in thermodynamics, and is described by Feynmann, Volume I 44-1.

Experiment 4.05 A soda-straw thermometer

It is difficult for students to understand the concept of temperature without a thermometer. Here is a simple experiment requiring only sticky tape, a soda straw, and a little water, which demonstrates Charles' law as well as giving the temperature.

Fold the end of a straw over two or three times as shown, and fasten it with sticky tape, (Fig. 1).

Fill the open end of the straw with about 5 cm of water (it may be easier to put the water in first, before sealing the other end). If you place the closed end in your mouth, you can see that the expanding hot air forces the water out. Remove the straw from the mouth, and notice how the air moves the water back up the tube (to its original position) as it cools. Now squirt cold water from the drinking fountain over the straw, or place it in a cold drink. The water will move way back.

The thermometer may be used quantitatively by marking the position of the water meniscus (with a pen) on the side away from the open end, first at room temperature, then for the ice cold water, for your mouth, and for very hot (preferably boiling) water. You can calibrate your thermometer on the basis of Charles' law, which states that the volume of air, or length of the air column, is proportional to its absolute temperature (temperature in °C + 273).written °K where K stands for Kelvin.

$$\frac{V_1}{V_2} = \frac{T_1 + 273}{T_2 + 273} = \frac{L_1}{L_2}$$

where V_1 is the volume and L_1 the length of the air column of temperature T_1°C, and V_2 and L_2 the corresponding values at T_2°C. Figure 2 shows typical measurements. The length of air at room temperature in this example T_r is 12.4 cm, for boiling water it is 16 cm, and for ice water 11.5 cm, and for body temperature T_B it is 13.2 cm.

$$\frac{\text{Temp °K}}{\text{Length of air}} = \frac{373}{16} = \frac{273}{11.5} = 23.5 = \frac{T_r}{12.4} = \frac{T_B}{13.2}$$

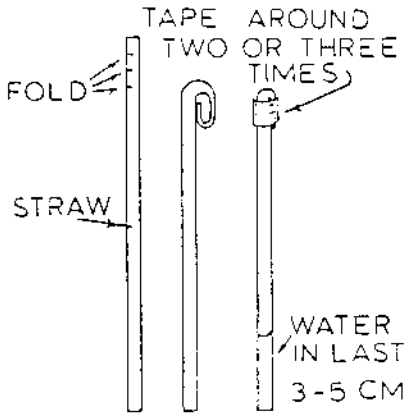


Fig. 1.

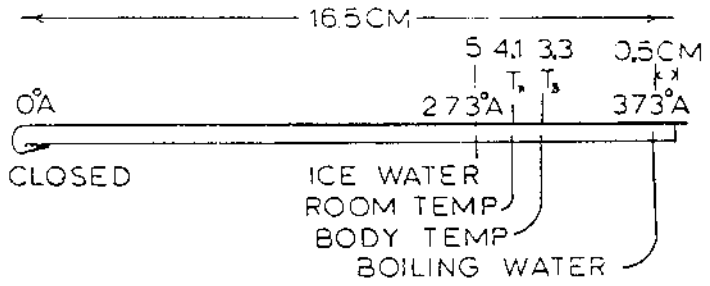


Fig. 2.

This gives room temperature as 291°K or 18°C, and body temperature as 310°A or 37°C. You can mark a linear scale (from 0 to 100) on the side of the thermometer if you can obtain the fixed points at 0°C and 100°C as described.

It is difficult to place the whole length of the straw in the mouth or cup. Unfold a paper clip, and drop it in the straw as shown in Fig. 3. The paper clip, within the straw, may then be bent to reduce the overall length.

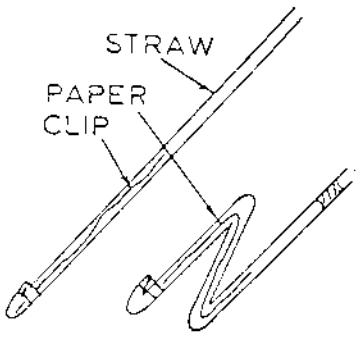
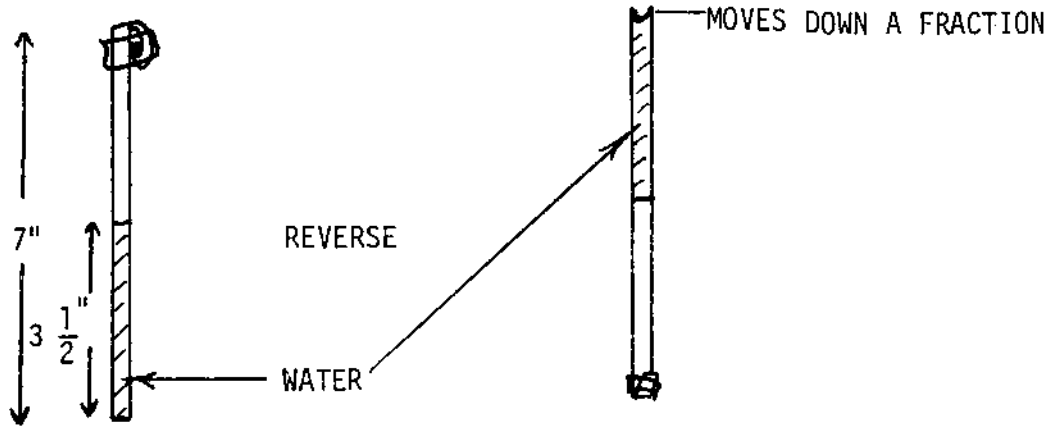


Fig. 3.

Experiment 4.06 The pressure-volume relationship in a gas

Materials: - Soda straw, water, tape

Procedure: - Fold over the end of the straw, twice, and wrap around with tape. Fill about half full with water. The straw will be about seven inches long, with about three and a half inches of water, as shown.



WATER FLUSH WITH THE END

The water should be flush with the end of the straw. Now invert the straw. Notice how the water compresses the air, and moves a fraction down the tube. Estimate how far down. On reversing the tube, the water should again be flush with the end.

Qualitative meaning: -

The air in the tube is under atmospheric pressure. When held with the open end upward, to the atmospheric pressure is added the pressure of the water in the tube, reducing the volume of air. Held upside down, the water pulls downward, reducing the pressure, and enlarging the volume of air, so the water runs toward the mouth of the tube a little.

Quantitative: -

Boyle's law states

$$pV = \text{constant}$$

When p is the pressure and V the volume. Atmospheric pressure is approximately 1,000,000 dynes per cm^2. A height of 1cm of water, since it gives 1 gm per cm^2, provides a pressure of 981 dynes/cm^2. If the straw has

9 cm of water in it, and the volume of air is proportioned to the length, say 9 cm, the fractional compression of the air or reversing the straw will correspond to a change from

$1{,}000{,}000 + 9 \times 981$, to $1{,}000{,}000 - 9 \times 981$

a change in length of $9 \times \frac{18 \times 981}{1{,}000{,}000}$ cm = .15 cm

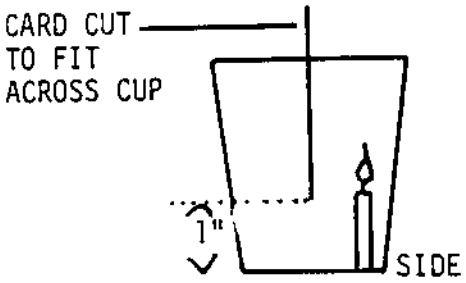
What is the length change you measured?

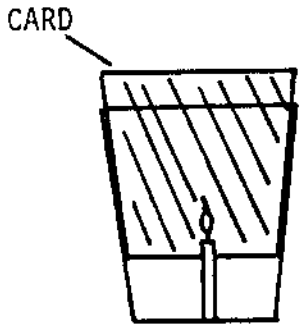
Experiment 4.07 Convection

Materials required: - Candle (a small birthday candle works best)

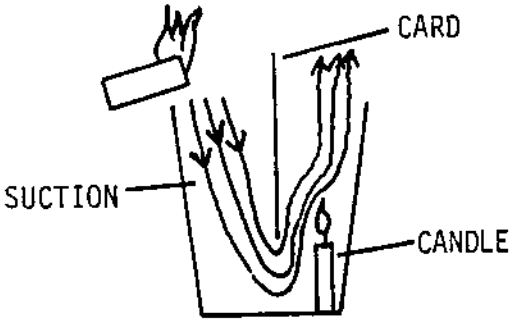
cup - sheet of cardboard, slightly damp paper - or, paper to make smoke.

Procedure : Cut the cardboard as shown to fit tightly in the dixie cup. Fasten a candle to one side of the cup and light it. After about two minutes, to allow the convection to build up, light the damp paper (paper towel works well) and observe the way the smoke is sucked down one side and goes up the other side with the candle.





FRONT VIEW

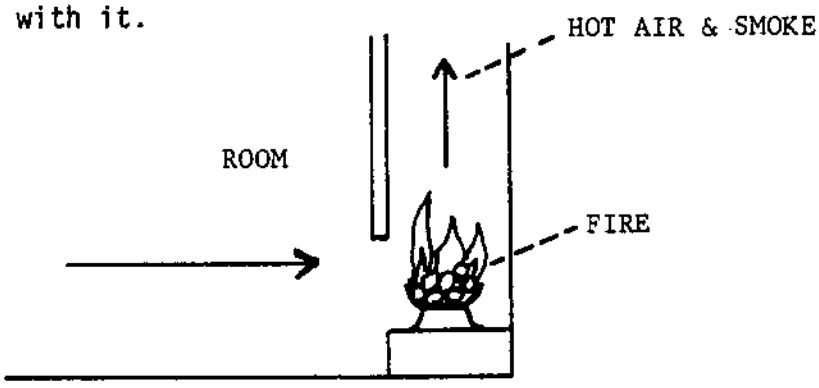


SIDE VIEW

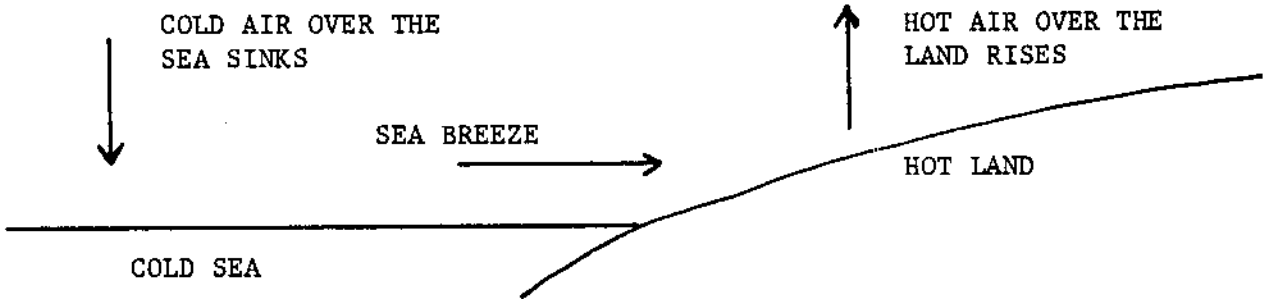
What you learn: -

Qualitative: - The hot air from the candle, being less dense, rises and draws the denser cold air from the other side of the card.

This is the principle by which the hot air rises up a chimney, and draws the smoke with it.



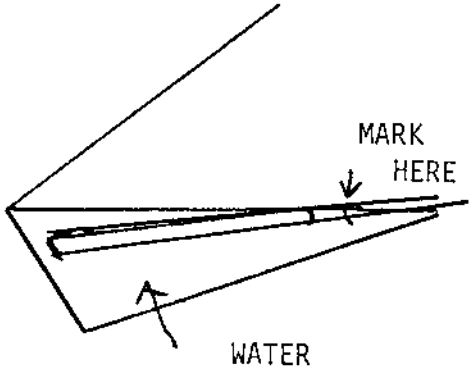
Also, the sea breeze during the day at the beach arises in the same way.



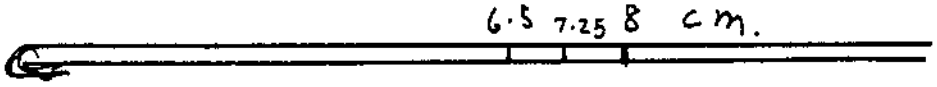
Experiment 4.08: Thermal Capacity

Materials: two styrofoam cups, thermometer.

Procedure: Half fill one cup with the coldest water. Place the soda straw thermometer in the water. Make sure the trapped air is covered. Mark the



position of the drop in the straw using a soft pencil or a fine marker pen. Half fill a second cup with the hottest water available, and again mark the position of the drop. Now mix the two, and measure the temperature of the mixture. Below is shown the positions marked in an actual experiment. Note



the temperature of the mixture is exactly half way between the temperature of the hot and cold water. Do you find this is so? Why is this?

The quantity of heat contained by water is proportional to the absolute temperature, and the mass of water. It is, in fact, the mass of water multiplied by the specific heat multiplied by the temperature, where the specific heat is the heat to raise the temperature of unit mass of the substance one degree. Since for water, it takes 1 calorie to raise its temperature 1°C, the specific heat of water is 1. At first we had two masses of water, M, at temperatures T_1 and T_2, a quantity of heat $MT_1 + MT_2$. After mixing, we had $2MT_3$. If no heat is lost,

$$2MT_3 = MT_1 + MT_2$$

or

$$T_3 = \frac{T_1 + T_2}{2}$$

This is what we found, and confirms our hypothesis that the quantity of heat is

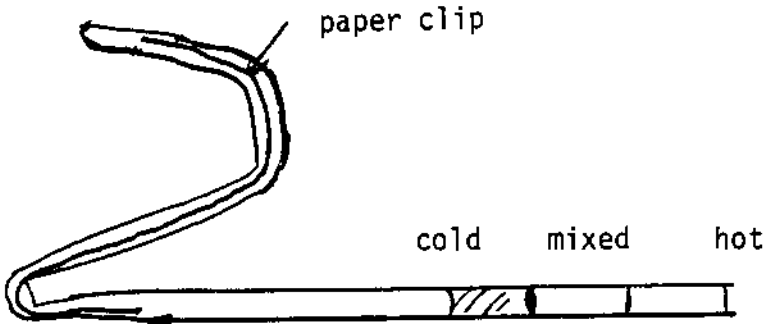
1) Proportional to the mass of water.

2) Proportional to the absolute temperature.

Further checks can be made using different masses of water, m_1 and m_2, when

$$T_3 = \frac{m_1T_1 + m_2T_2}{m_1 + m_2}$$

The sensitivity may be improved by using the folded straw as thermometer.



Experiment 4.09. Cooling a cup of coffee. Rate of cooling of a body and thermal conductivity of styrofoam.

Materials: Styrofoam cup, hot water, thermometer.

Procedure: Much about heat can be learned from the way a cup of coffee cools. You will need a Styrofoam cup filled brimful with hot coffee (hot tea or water will do) and the soda straw thermometer (or a regular thermometer)(4.05)made by folding over and taping one end of a straw, and putting a little water in the other end. The straw has an opened up paper clip inside, bent so the drop moves horizontally and does not run out. Make a mark on the straw, using a soft pencil or fine marker pen at the position of the water drop, making sure the coffee covers most of the straw, as shown in Fig. 1. Make readings every five minutes as the coffee cools. Plot the length between the position of the drop at room temperature, and that at a given time as it cools against the time, as shown in Fig. 2. The qualitative question requiring an answer is why the liquid cools faster at first, when hot, than later on, as it reaches room temperature. Does it cool faster with less coffee in the cup? Does covering the top with a piece of paper or a handkershief slow down the rate of cooling, and if so, why? You will find for example, that covering the top with a book cuts the rate of cooling in half, showing that half the heat is lost from the open surface of the coffee.

Quantitatively, Newton discovered that the rate at which heat is lost by conduction is proportional to the temperature above the surroundings T. The rate of heat loss is proportional to the rate of fall of temperature (dT/dt) which is given by the slope of a line tangent to the graph, such as AC. If Newton's law is true, any series of such tangents should strike the axis at a constant distance BC from the point at which a perpendicular AB, dropped from the curve where the tangent touches it, strikes the X axis. Hence, BC = EF, etc.

Now if the time BC = τ, then

$$\frac{dT}{dt} = -\frac{T}{\tau}$$

or $$-dT/T = dt/\tau$$

Integrating $\ln T = -t/\tau + C$ (where C is a constant)

$$T = C \exp(-t/\tau)$$

τ is approximately 30 minutes with the top open, and 70 minutes with the top covered with a book.

The insulating qualities of a Styrofoam cup ensure that the outside of the cup is almost at room temperature. One can then use cooling to estimate the heat conductivity of the foam. For a six-ounce cup (177 cc) the surface area A is approximately 170 cm^2, and the thickness, d, 0.2 cm. The rate at which heat is conducted across the surface of the cup per second is

$$dQ/dt = kAT/d$$

where k is the conductivity, the heat per unit time crossing the opposite faces of a unit cube of the substance having a one degree temperature drop between those faces.

The specific heat of the water or coffee C is 1 cal/gm, the density S is 1gm./cc.,the volume of the cup is V cc.,so $(dQ/dt)=-VSC(dT/dt)=-V(dT/dt)$ cal/sec

Therefore $dT/dt = -(kAT)/Vd$

Since $\frac{dT}{dt} = -\frac{T}{\tau}$

$$(dT/dt)/T = -kA/Vd = -1/\tau$$

or $$\tau = Vd/kA$$

so $$k = Vd/A\tau$$

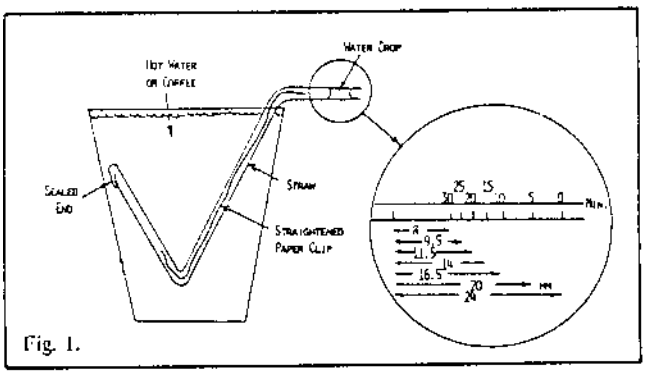


Fig. 1.

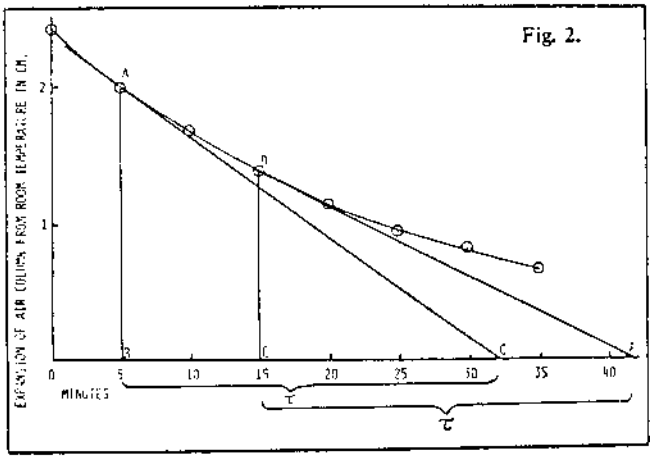


Fig. 2.

The conductivity of foam found by this technique is about 0.00006 cal/(sec, cm, °C) provided heat is prevented from escaping from the top of the cup by putting a book on it. Essentially we are measuring the thermal conductivity of air, which is 0.000057 cal/(sec, cm, °C), because the pores of the Styrofoam are air filled. Each pocket of air is restricted to its cell and cannot remove heat by convection as it does outside the cup.

One can show that the quantity of heat that can be extracted from a body is proportional to its temperature, its mass, and its specific heat using Styrofoam cups, too. Half fill two cups, one with the coldest water, and the other with the hottest water available. Mark the position of the thermometer water drop when it is placed in the two cups (Fig. 3). Make sure the enclosed air is covered. Now mix the two and measure the new temperature. This should lie halfway between the hot and the cold. If we use different

masses of water, M_1 and M_2 (use a spoon, or other measuring device, to ladle different known quantities into the cups), the temperature of the mixture is given by

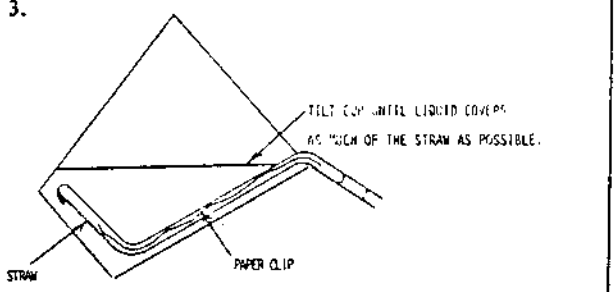
$$T_3 = (M_1T_1 + M_2T_2)/(M_1 + M_2)$$

We can now extend this to different materials. Glycol (antifreeze) makes an interesting example. The quantity of heat transferred from a body is also proportional to its specific heat σ giving us

$$T_3 = (m_1\sigma_1T_1 + M_2\sigma_2T_2)/(M_1\sigma_1 + M_2\sigma_2)$$

where we replace one cup of water, specific heat $\sigma_1 = 1$ with antifreeze, $\sigma_2 = 0.56$. Many common organic liquids (e.g., ethyl and propyl Alcohol) have densities near enough to one, and specific heats of about a half. Avoid liquids giving out heat chemically when mixed with water. The results show immediately that antifreeze cannot absorb as much heat as water for a given temperature rise, which is a disadvantage as a cooling agent.

Fig. 3.



Experiment 4.10 - Relative Humidity with a Drinking Straw Thermometer

Materials: straw, styrofoam cups, tape, paper towels, ice, boiling water

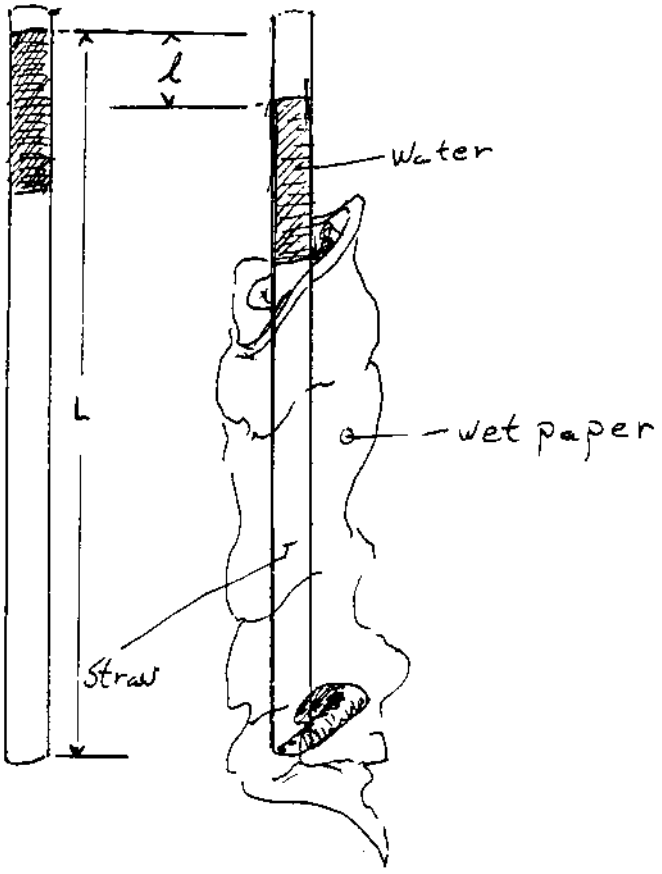
Purpose: to demonstrate how a wet bulb thermometer works and is used to find the relative humidity

Procedure: When asked to measure distances on the straw, always measure to the nearest tenth of a cm.

Place the straw in a cup of water. Allow the straw to fill with water up to about 2 or 3 inches. Put your finger over the top of the straw and remove it from the cup. Turn the straw upside down so that the water is at the top. Fold over the bottom of the straw 2 or 3 times and tape it down. Mark the position of the top end of the water drop.

Wrap a wet paper towel, or wet toilet paper, around the straw until the top end of the water drop is just visible. Wave the straw about gently, and mark the lowest point the water drop reaches, when the straw is held steady.

Measure the distance between the two marks ℓ on the straw and enter it in your notebook. Also measure the distance from the closed end of the straw to the bottom of the drop, L.



R. Bennett

If we assume room temperature is about 75°F, (24°C) this is 297°K, Charles' gas law tells us the volume of a gas is proportional to its temperature, so in our case, where the volume is proportional to the length, the change in temperature produced by the wet paper is

$$\frac{\ell}{L} \times (297°K)$$

If t is the temperature in °F, the lowering in temperature in °F is given by

$$\frac{\ell}{L} \times (t + 460)$$

The relative humidity may then be found from the table. To give an example, suppose the air column were 18 cm long, and on cooling became 17.6 cm long. If room temperature t were 75°F, the drop in temperature would be 11.9°F corresponding to a relative humidity of 44%.

RELATIVE HUMIDITY

Air temp (°F)	Lowering of wet-bulb thermometer (°F)																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1										
65	95	90	85	80	75	70	66	61	56	52	48	44	39	35	31	27	24	20	16	12	9	5	2								
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3						
75	96	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34	30	27	24	21	18	15	12	9	7	4	1			
8	90	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	

Experiment 4.11 The Mechanical Equivalent of Heat

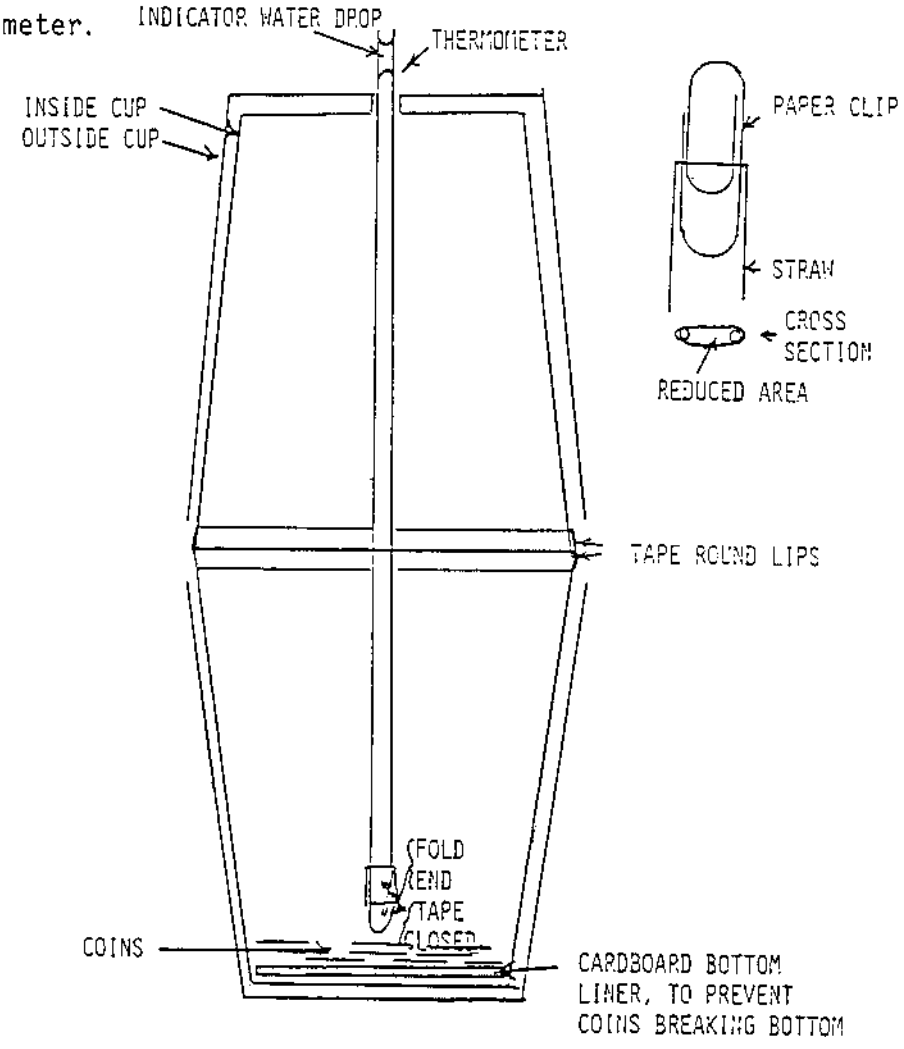
20-30 pennies, 4 styrofoam cups and a thermometer are the only objects required for this experiment.

Make sure everything is at room temperature by leaving it out several hours. Cut a circle of card to fit inside the bottom of the lower cup. Place the coins in one cup, and tape the other cup on top, open ends together as shown in the figure. Push the other two cups over the first two to improve the thermal insulation. Shake the cups so that the coins fall from the top of the top cup to the bottom of the bottom cup 400 times. This takes about three minutes. Since the cups are each 8 cm high the coins fall 2 x 8 x 400 cm or 64 m. If the total mass of the coins is m kg, the work done is mgh which is m x 628 J. h is the height they fall, g the gravitational constant (9.8 m/s^2). Make a small hole in the top cups and poke a thermometer through to measure the rise in temperature of the coins. Let this be t. The heat delivered to the coins is tjmc where j is the mechanical equivalent of heat in Joules/cal and c is the specific heat of the copper, 0.093 cal/gm K. or 93.0 cal/kgK. The specific heat depends on the constitution of the coins. From 1864-1982 American pennies were 95% Cu and 5% Zn. Since then they are 95% Zn, 5% Cu. Luckily, zinc has almost the same specific heat as copper, (.0925 versus .0921) so one can ignore the differences. The mechanical equivalent of heat is given by

$$j = nmgh/mct$$
$$= 628/93t \text{ Joules/cal}$$

If j = 4.18 J/cal., t must be 1.6°C. In fact, we find values of j much smaller than this probably because the tendency is to shake the cups too hard, and generate more energy than given by the pennies falling only 16 cm each shake. The advantage of using coins is that the specific heat being so low, the

temperature rise is high. The double walled styrofoam prevents the heat leaking out, and the specific heat of the air in the container is negligible. Nevertheless, it can take several minutes before the maximum temperature is reached in the container. A regular mercury thermometer graduated in tenths of a degree is best, but if a drinking straw thermometer 16 cm long is used (a standard length for straws) the water drop at the top of the drinking straw will move a distance of 16 $(\frac{301.6}{300} - 1)$ cm = 0.085 cm which is barely measurable. How can one improve the sensitivity of the thermometer? If you push a large paper clip into the open end of the thermometer, it will spread the circular opening into a flat oval, as shown in the figure, reducing the area by a factor of two or three. The sensitivity of the device is increased by a corresponding amount, but it must now be calibrated against a standard drinking straw thermometer.



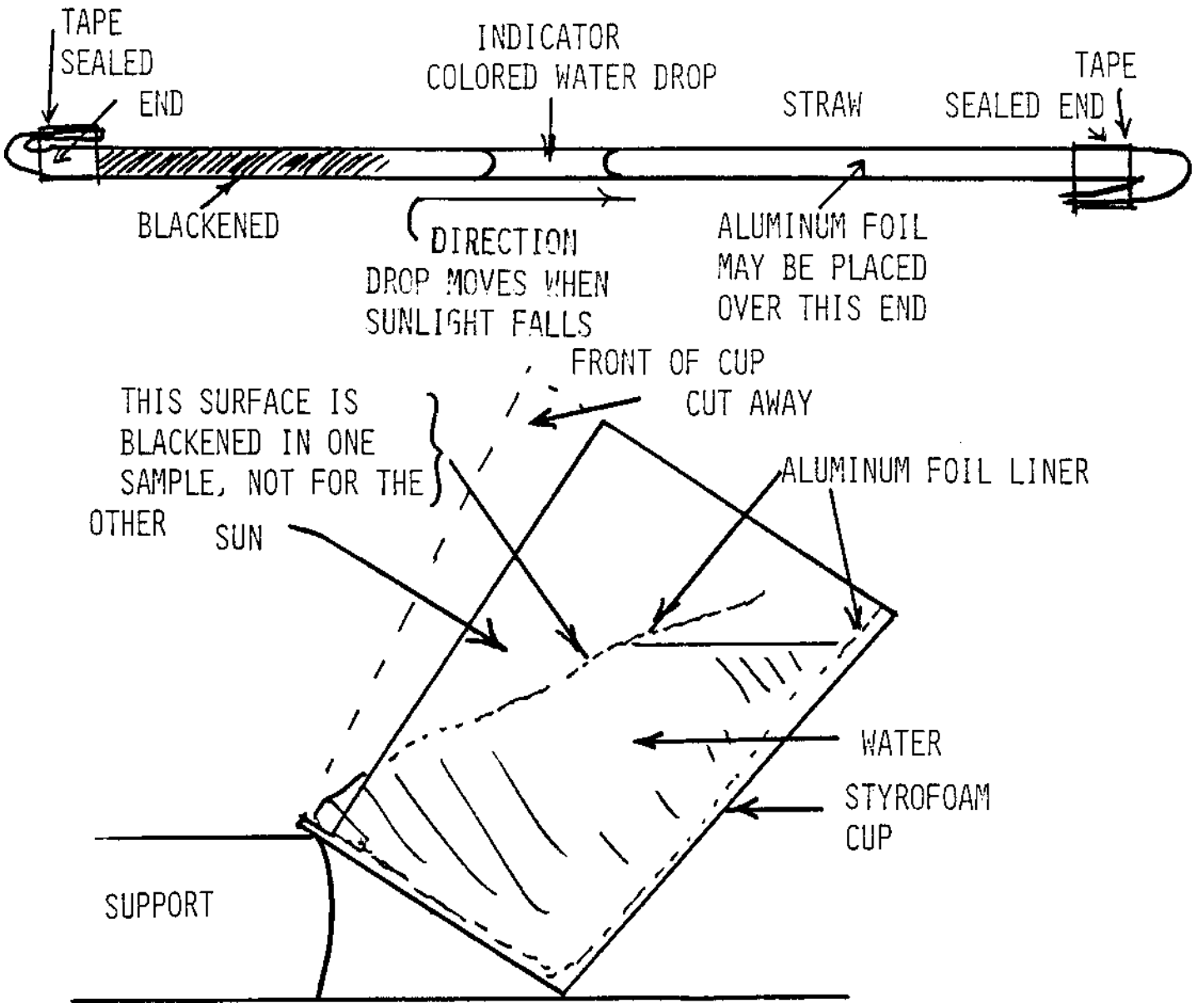
Experiment 4.12 Absorption and Emission of Radiation

We have seen how heat may be transferred by conduction - in a previous experiment the heat is conducted through the styrofoam cup on cooling a cup of coffee, the foam behaving essentially as air unable to convect, which has a low conductivity - a paper cup cools much more rapidly, because conduction through paper is rapid. Convection was demonstrated with the candle in the cup having a vertical division - but what about radiation? This experiment can only be performed on a sunny day. A very simple demonstration consists of a single straw, with a drop of colored water (ink, Coke etc.) in the middle as shown in figure 1. The ends are folded over and sealed with tape, to ensure they are air tight, then one end is blackened, preferably with soot from a burning candle or damp paper, but if not, then with a pen or marker. Then place the device in the sun - the drop moves away from the blackened end, because of the expansion of the hot air. To improve the effect, cover the unblackened end with aluminum foil. For a more quantitative experiment, take two styrofoam cups, cut one side off each one, as shown, and line them with aluminum foil. Blacken one of the foil liners over the aperture, as before. Put the same amount of water in each cup liner - enough to half fill them, and tilt to face the sun - best at noon. The styrofoam cup is merely to prevent heat escaping from the rear of the device. After a few minutes, measure the temperature of each cup, using a thermometer (the drinking straw thermometer from previous experiments works well). The black coated cup heats up much more rapidly. These experiments have the advantage that it is clear the sun is providing the heat through radiation, and not in any other way. One can get a crude value for the solar constant (the energy delivered per unit area and time by the sun at the distance of the earth's

orbit) by dividing the mass of water times the temperature by the time multiplied by the absorptive area. The constant is 2 cal/cm^2/sec, but you will get much less than this. Why?

An interesting example of solar radiation is the solar hot air balloon. Take a very thin (the cheapest kind!) black garbage bag, or better till a black garmet bag fill with air, seal the open end with thin thread, which is also the tether. Fill only to about 80% - the air must have room to expand. Put in the sun - morning is best, when the ambient air is cool, on a very still day. The bag will rise up as a hot air balloon - it takes about ten minutes to get hot enough. Rotate the bag to heat uniformly.

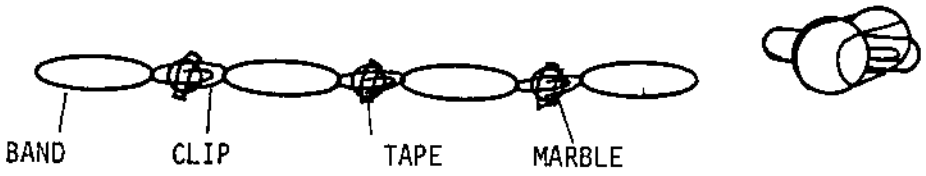
Emission of radiation is detected by filling a plastic (not styrofoam) cup with hot water, covering one side with black paper, and the other with aluminum foil. Hold a black coated straw themometer an inch or two from the aluminum face, and the black face, and note the difference. Even more simply, use your hand as the source of heat, put a flat sheet of aluminum foil vertically against your hand, and measure the temperature an inch or so away horizontally. Do the same with black paper. Note the black paper radiates more.


TAPE SEALED END
INDICATOR COLORED WATER DROP
STRAW
TAPE SEALED END
BLACKENED
DIRECTION DROP MOVES WHEN SUNLIGHT FALLS
ALUMINUM FOIL MAY BE PLACED OVER THIS END
FRONT OF CUP CUT AWAY
THIS SURFACE IS BLACKENED IN ONE SAMPLE, NOT FOR THE OTHER
SUN
ALUMINUM FOIL LINER
WATER
STYROFOAM CUP
SUPPORT

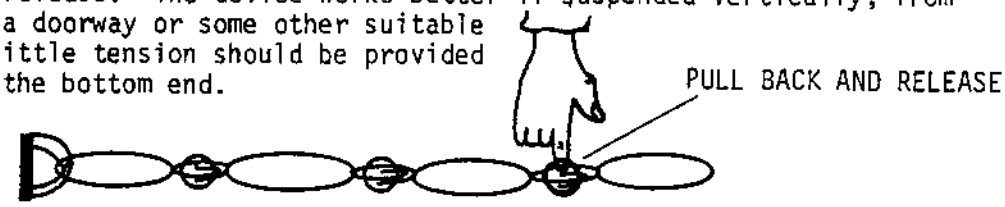
Experiment 5.01 Longitudinal Waves

Materials: - rubber bands, marbles, paper clips tape

Instructions: - The aim of the experiment is to construct a device along which longitudinal waves travel slowly, so that the motion may be followed in detail. Connect sixteen paper clips in a string using sixteen rubber bands, to provide a weak restoring force. To slow the longitudinal wave, attach two marbles to each paper clip with sticky tape.



Now, attach both ends to a firm anchor - you can fasten one end to your desk and hold the other with your left hand. With your right, pull back the last marble and release. The device works better if suspended vertically, from the top of a doorway or some other suitable point. A little tension should be provided by hand at the bottom end.

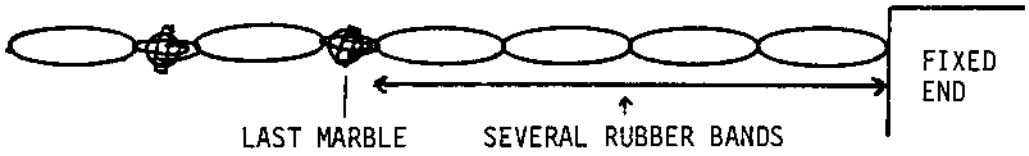


Watch the compressive pulse travel along and be reflected. We call it compressive because each marble moves in the direction the wave travels, pushing the one ahead. After reflection; is the pulse compressive? It is often difficult to follow the pulse down the string, but if you watch the end marble closely, you will see it jerk backwards and forwards each time the pulse passes.

A rarefaction occurs where the marbles move in a direction opposite to that in which the pulse travels - so if you move the marble away from your left hand before releasing, you get a rarefaction traveling down the system. Sound waves in air are composed of successive compressions and rarefactions. You have looked at reflection from a fixed end. Such reflections occur with sound waves in organ pipes closed at one end. Standing waves are built up in such pipes. You can simulate such a standing wave by moving the hand holding the rubber band backwards and forwards until you hit a resonance. The marble

near the far end must be stationary. This is called a node. The marble in the middle moves rapidly, which is called an antinode.

To examine what happens if we have an open organ pipe, attach three or four rubber bands without marbles or paper clips between the far end of the string and the table.



Now, if you feed in a compressive pulse, is it reflected as a compression or a rarefaction? Try producing standing waves You will find the end marble, which was stationary, now moves more than all the rest - so what was a node for a closed pipe, is an antinode for an open one. This arrangement can also be used for transverse waves, but the soda straw device, mentioned elsewhere, works better.

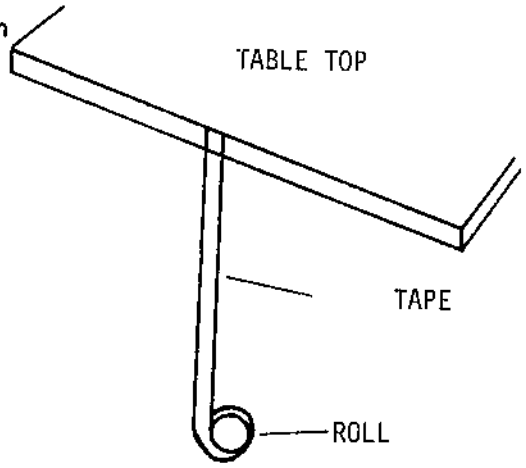
Torsional Waves

If the device is hung vertically from a support, torsional waves may be generated by rapidly twisting the lowest rubber band by rubbing it between the thumb and forefinger. The bottom clip and marbles spin rapidly, and pass this motion very slowly to the top of the chain. Here the pulse reverses and the marbles spin in the opposite sense. Reaching the bottom, which reflects like an open ended pipe, the marbles continue to spin, and wind up in the same sense, the pulse again traveling up the chain and reversing at the top. This proves a dramatic demonstration of the difference between reflection at an open and closed end.

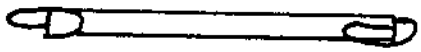
Experiment 5.02 Transverse Waves

Materials: Sticky-tape, about two dozen drinking straws, paper clips.

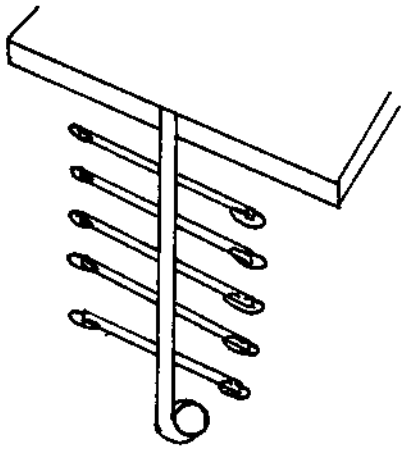
Procedure - Attach one end of the tape to the table top, pull about two feet off and let it hang down



Place one paper clip in each end of each drinking straw

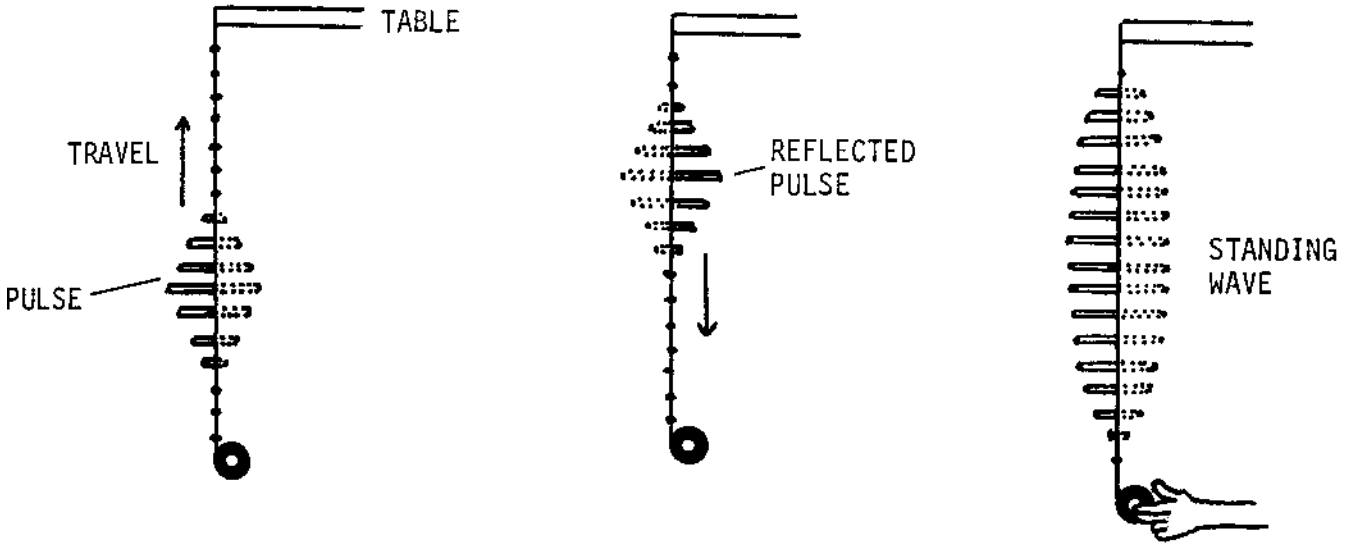


Stick the center of the straws at one inch intervals along the sticky tape, until you

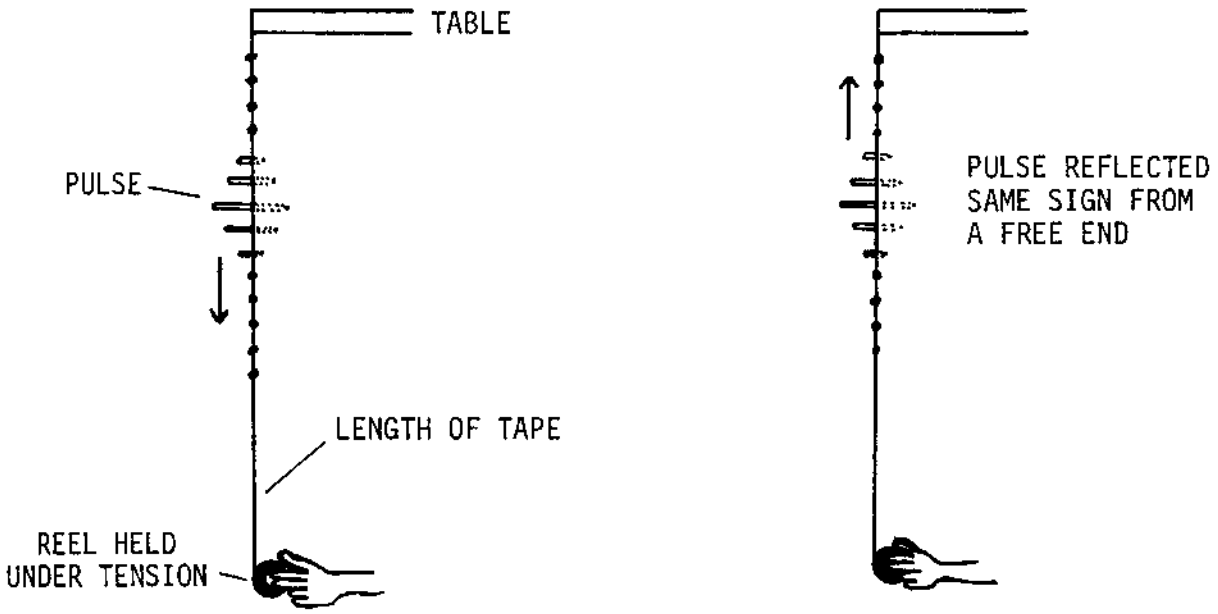


have about 24 of them attached. Now, looking end on at the straws, pull the tape reel, to make the strip taut, and give the bottom straw a tap. You will see a transverse wave

pulse travel up the strip, and be reflected at the top

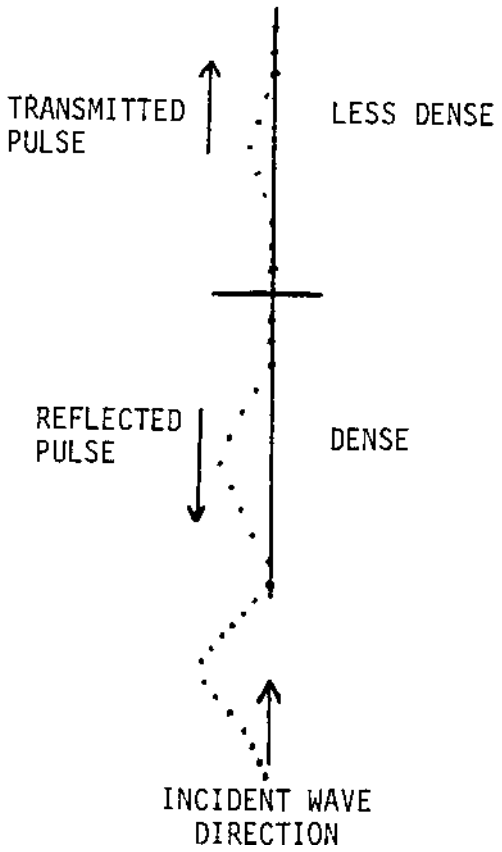


You may induce standing waves by rotating the bottom straw too and fro with the right period. If you unreel a length of tape, you may study reflection from a free end, just as you did reflection from a fixed end



For the last foot or so of the tape, put two paper clips at each end. Now you can study the reflection of a wave traveling from a less dense to a denser medium (top to bottom) or vice versa (bottom to top). Note how, in each case, part of the wave is reflected at the intersection; but in one case it changes sign (phase)

and in the other case it does not.



Experiment 5.03 Twin Slit Diffraction

Materials: ruler, pencil, protractor, scissors

Procedure: Cut out the four sheets having the white semicircles on them. The white dot on the bottom of each sheet represents a source of circular waves, the rest of the pattern being similar to that produced by a point source in a ripple tank, (or a monochromatic line source of sound or light). The long vertical line below this point is to help identify the source, and several additional lines have been placed to the right and left as reference.

The separation between two white circles is one wavelength. Take the two sheets with the smaller wavelength, and place them face to face, with the two white dots touching one another. Look through the two sheets, by holding them up to a window pane, or to some other light source. You will see figure 1. Slowly slide one sheet over the other to separate the sources horizontally, and obtain the rest of the patterns shown. The bright central line arises because there is a maximum of intensity here. Each point on the central line is the same distance from each source, so the waves always arrive here in phase, each crest or trough constructively adding to the one from the other source. Away from the center, the waves arrive out of phase--the crest from one wave arrives at the same time as the trough from the other. However, if we separate the sources by a distance greater than λ, we see two further bright lines, which arise because the distance from each point on this line to one source is exactly one wavelength more or less than it is to the other, so that again, the crests and troughs from both sources arrive at the same time. Further out are other bright lines where the difference of path length to one source is exactly two wavelengths more or less than to the other. Draw lines on the sheet of paper where the bright line is with the sources separated by 2λ, and answer the following questions:

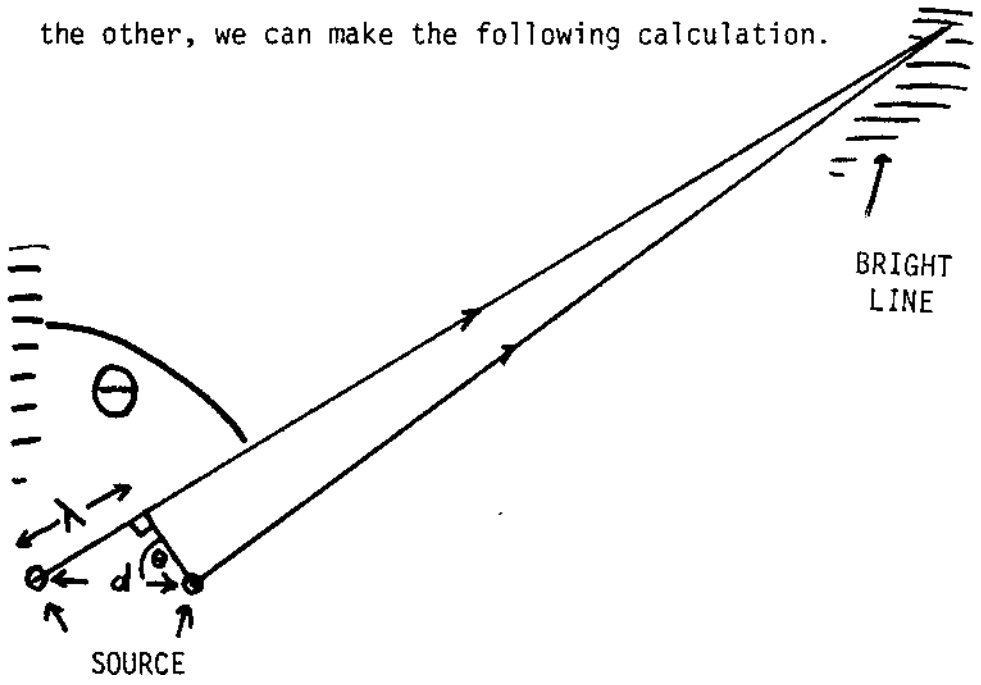
1) As you separate the sources, do the bright lines move inward (i.e. closer together) or outward?

2) Separate the sources to 4λ. What is the relationship of the new bright lines to those you drew separated by 2λ? Do you find that doubling the separation of the sources halves the angle between the lines? As you separate the slits how many sets of bright lines do you see? This would show an inverse or reciprocal relationship between the diffraction pattern and the separation of the source.

3) Now take the second set of semicircles, and note that the wavelength of these is twice that used previously. Again, superpose them face to face, and compare the pattern produced when the sources are separated by a fixed number of markers, say two, with that using the shorter wavelength sheets having the sources separated by the same amount.

   Do you find the bright lines spread out as the wavelength increases? If so, does the pattern double in width if the wavelength doubles? This would show that the pattern width is roughly proportional to the wavelength.

4) Measure the angle between the center bright line, and one of those you drew with the sources 2λ apart. If one source is λ further from the line than the other, we can make the following calculation.



From the diagram, approximately $\sin\theta = \frac{\lambda}{d}$ (if the first line is sufficiently far away).

Then $d = 2\lambda$

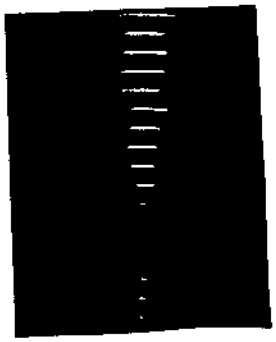
so $\sin\theta = \frac{1}{2}$ or $\theta = 30°$

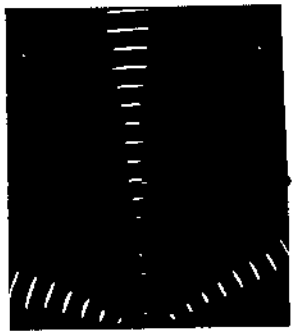
How close is your measurement to this? Why does it not agree exactly?

You can regard the shorter wavelength as blue light, and the larger as red, since these are roughly a factor of two apart, or you could think of the larger wavelength as middle C, and the shorter as the C above this, since these are a factor of two, an octave apart.

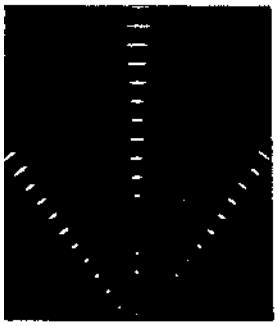
Metrologic, the company who first produced this type of diagram, suggested using twin slits in front of a laser to demonstrate the effect.using light, but for sound you could use twin speakers fed by a constant tone, and note the increase and decrease in sound volume as you walk across the room because of constructive and destructive sound interference.

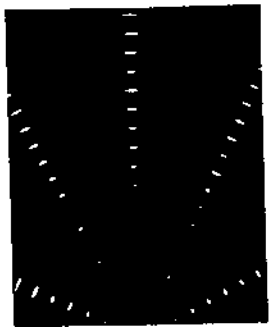
Fig. 1

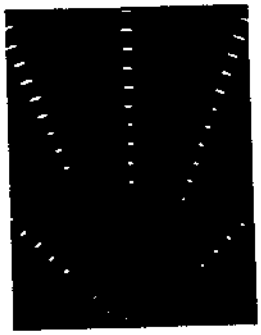


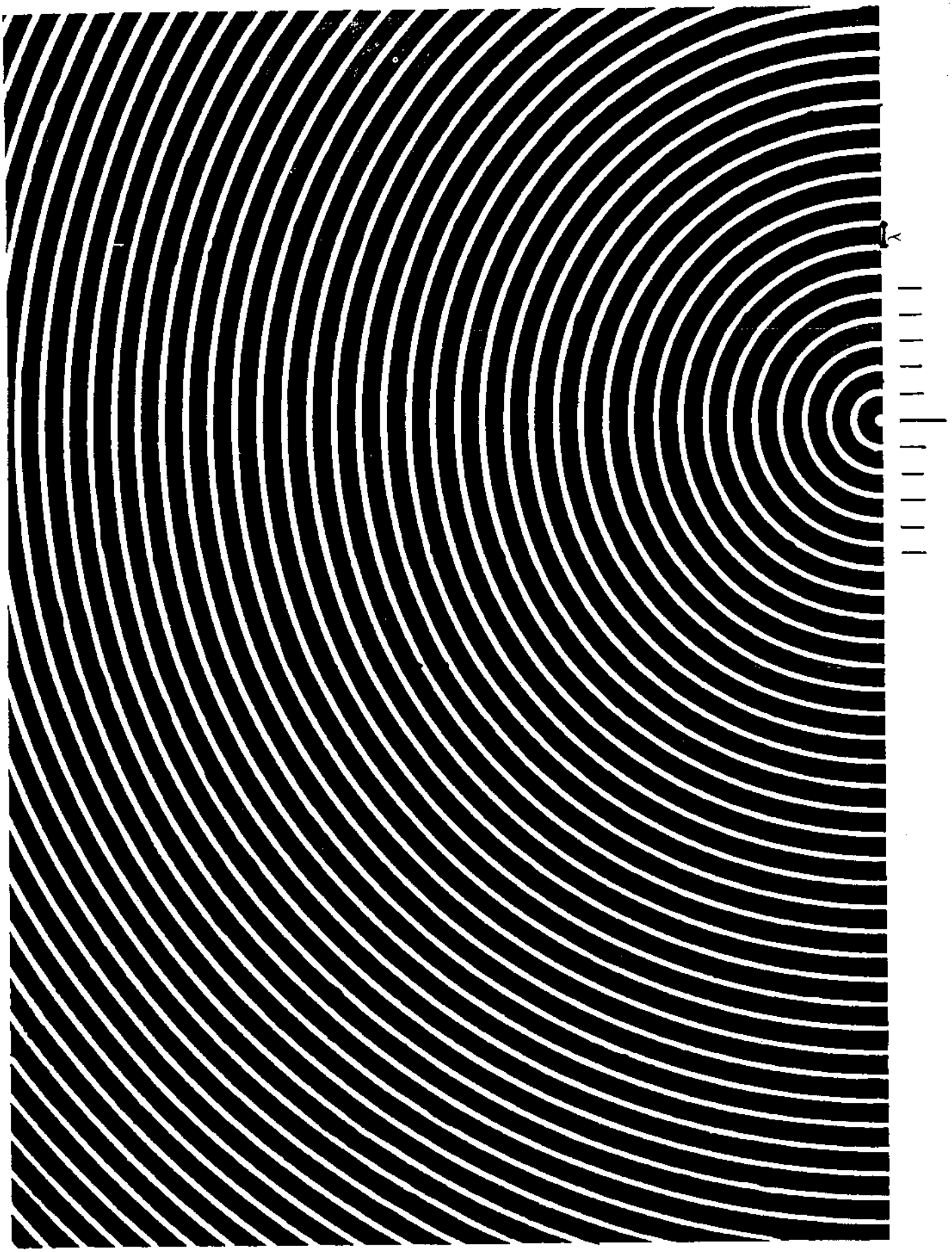


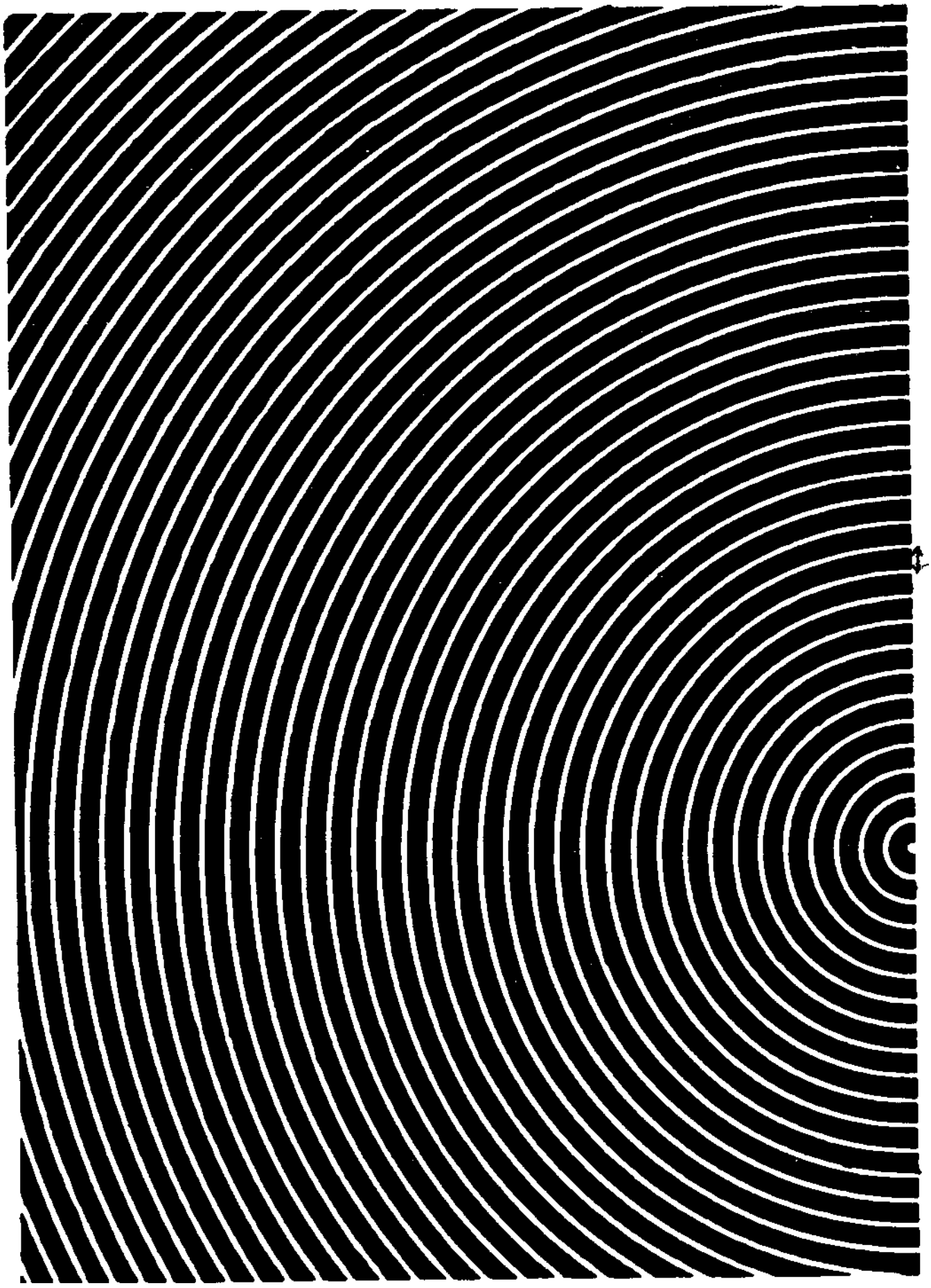
$d = \lambda$

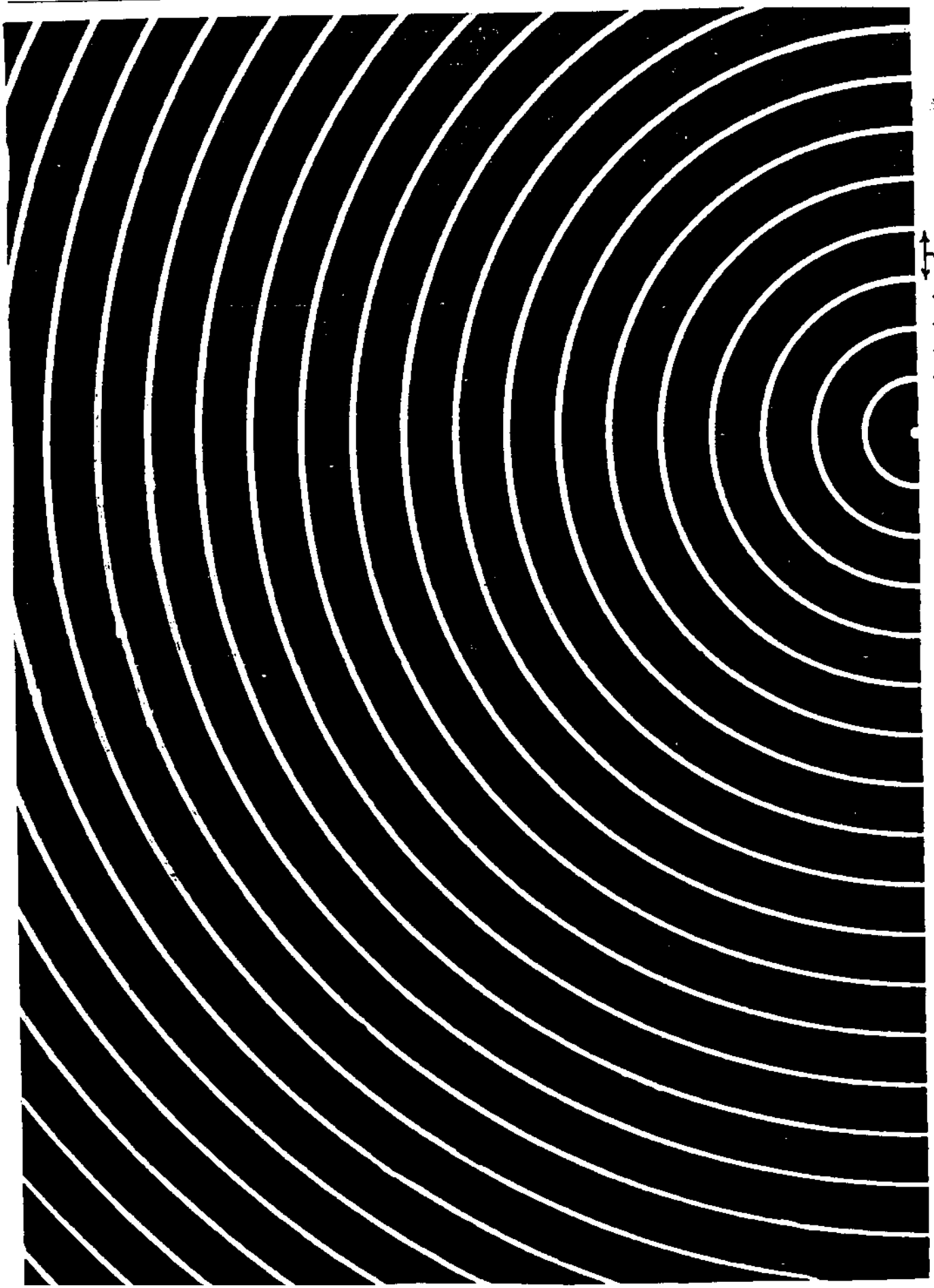


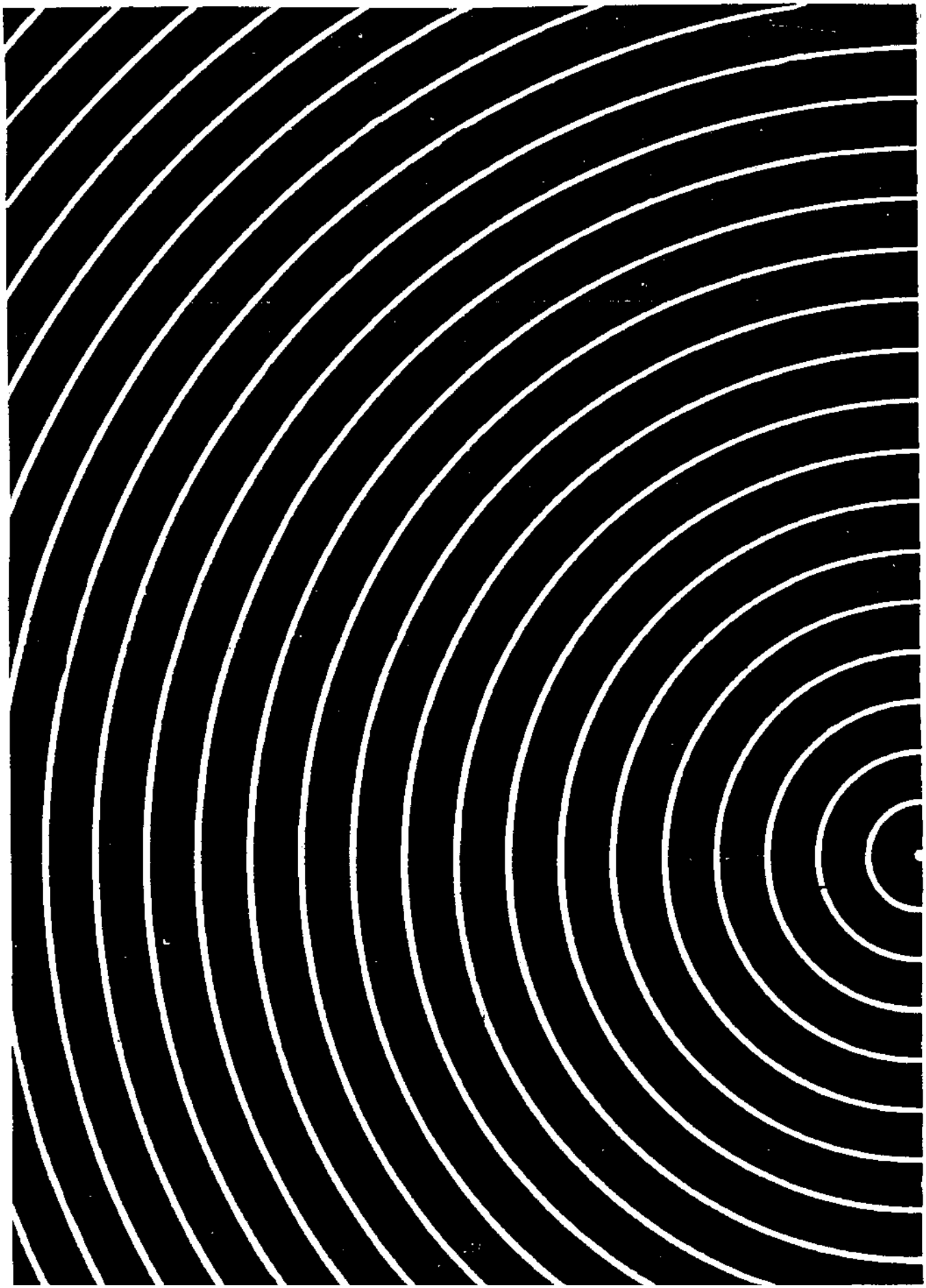








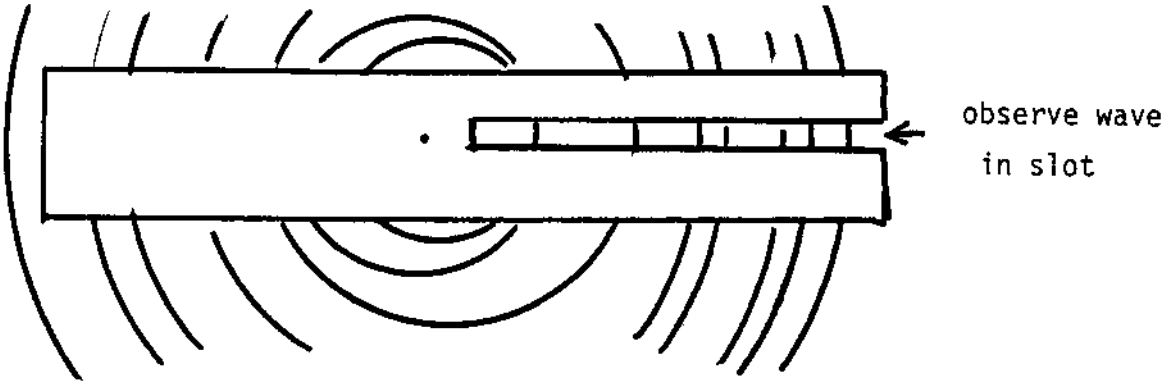




Experiment 5.04 Longitudinal Waves - Crova's Disc 1

Materials - Scissors, pin.

Procedure: It is sometimes difficult to visualize the process by which longitudinal waves, both travelling and standing, progress. Crova's discs have the advantage that the motion can be made as slow as one wishes. Cut out the disc labelled A, which represents travelling waves. The other disc, stationary waves, will be on the reverse side. Cut out the slot, and push a pin through the point labelled B, through the center of the disc, and into some suitable object, such as a desk or table. The disc, as seen through the slot, should appear as below:



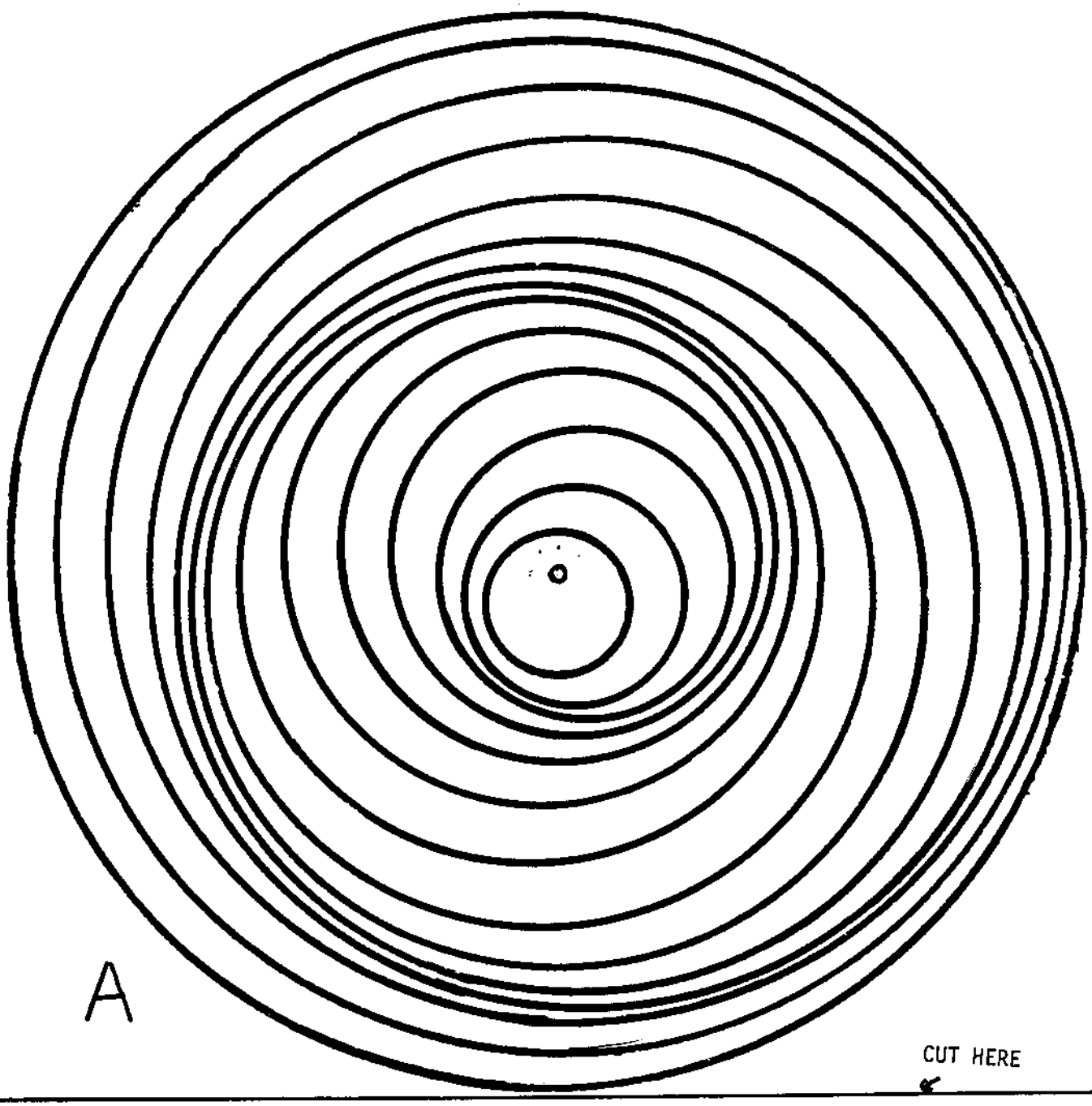
The wave is supposed to take place longitudinally in this slot, as would air in an organ pipe.
Now rotate the disc under the slot. Each pair of lines separates a layer of gas, say, and the motion of this layer, its compression and expansion, can easily be seen, the compressed layer pushing the next layer, and so on. When the standing wave is placed in the slot, it has a node at each end, and two nodes in the middle. The positions of these are marked on the slit.

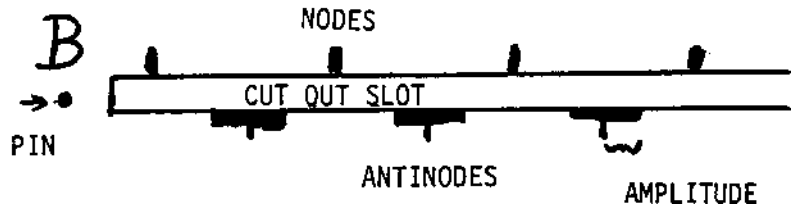
What is the wavelength of the two waves, in centimeters, and what is the amplitude of the excursion?

The wavelength of the travelling wave is the distance between successive compressions, (where the lines in the slot come closest to one another). It is also the distance between successive rarefactions. This corresponds to the distance between crests , or the distance between troughs in a transverse wave.

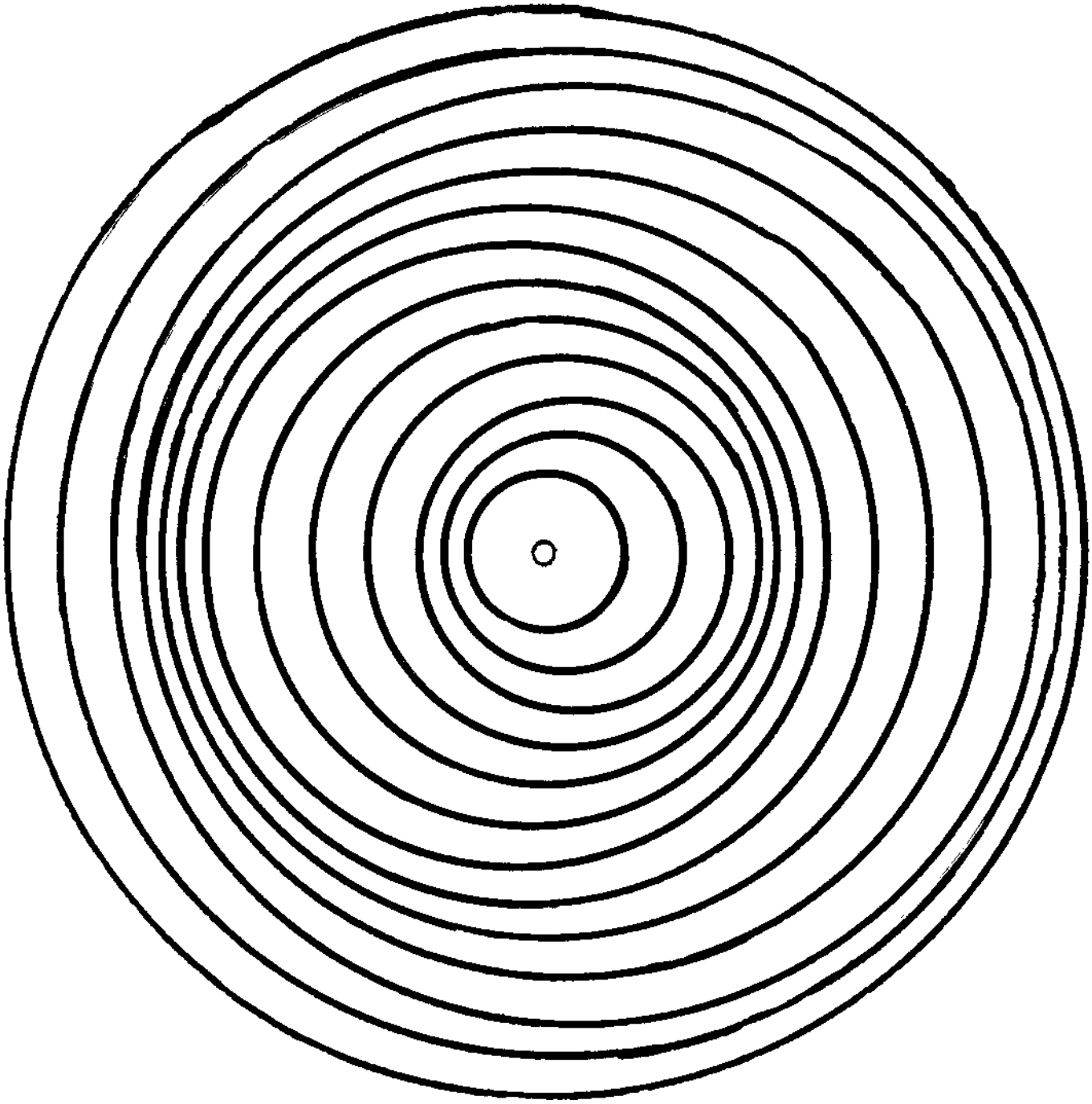
The amplitude of the excursion can be found in the travelling wave by noticing that each line in the slot moves backward and forward. There is no net motion of the lines, as there is of the wave. Make a mark at the edge of the slot where any one line is furthest to the right. Now rotate the disc until it is furthest to the left, and make another mark. The distance between these marks represents the maximum excursion of this line, and half this (i.e. from the center to the maximum, or minimum) is the amplitude of the wave.

The wavelength for a standing wave is twice the distance between nodes (where there is no motion of the air or of the line in the simulation) or twice the distance between antinodes (where maximum movement of the line in the slot occurs). The amplitude at the antinodes can be found by marking the slot when the line at the antinode is farthest right, and doing the same with it farthest left. The distance between the two marks is twice the amplitude of the wave.


A
CUT HERE


B
NODES
CUT OUT SLOT
PIN
ANTINODES
AMPLITUDE

STANDING WAVE



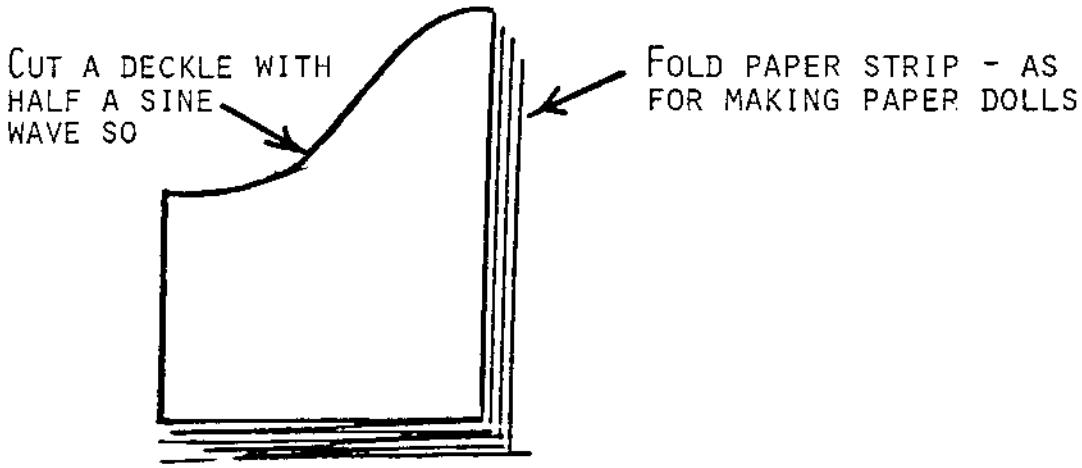
5.05 YOUNG'S SLITS WITH PAPER WAVES

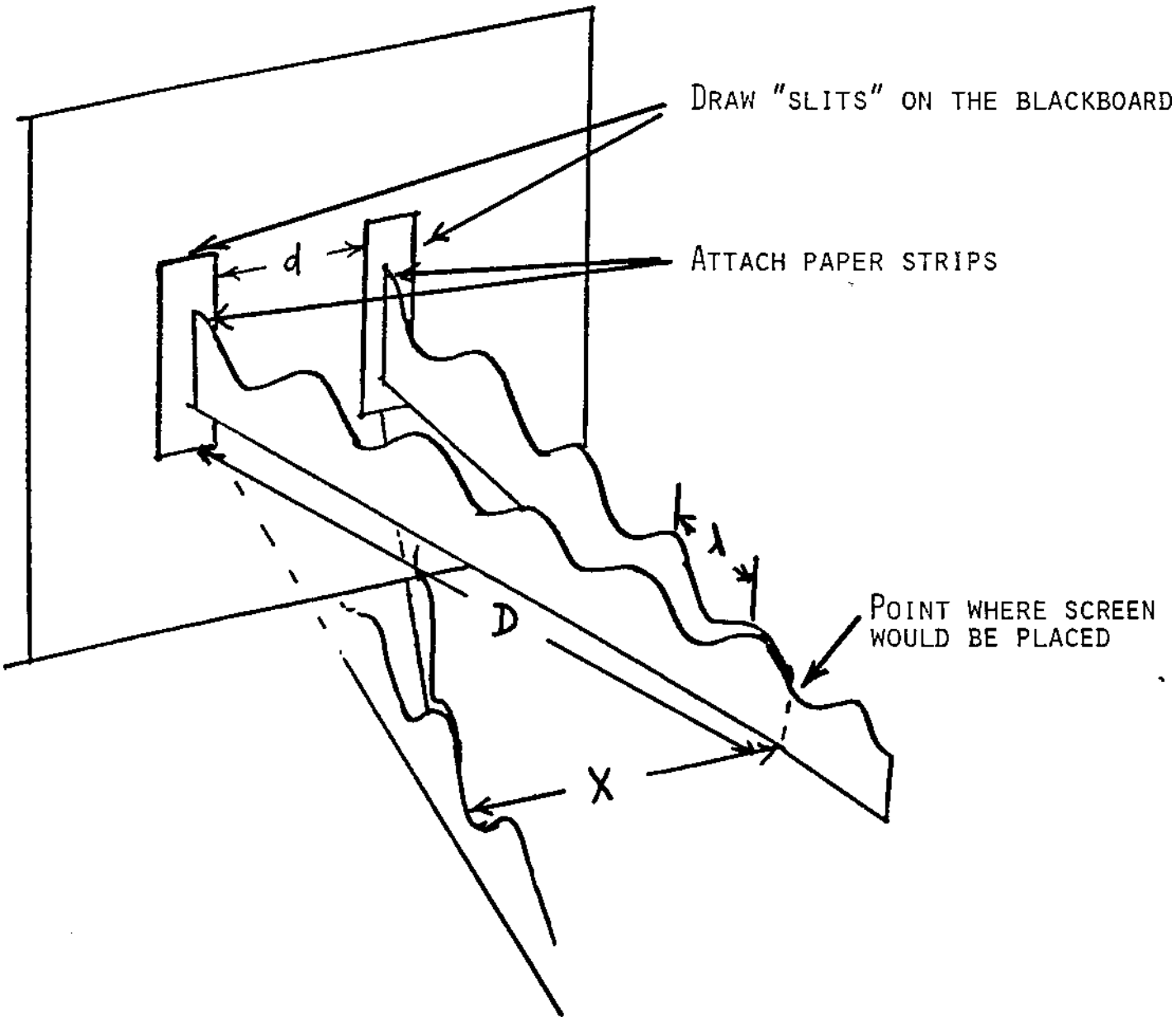
The Moire pattern method of demenstrating Young's slits is expressive, but an even simpler way uses long strips of paper.[1] Cut two long strips of paper from a newspaper, or a brown paper wrapper. Fold them too and fro and cut a waveform out of them much as one does in making paper dolls. Unfold the strips and tape the ends to two "slits" drawn on the wall, or blackboard as shown. Hold the opposite ends of the strips. The paper waves represent an instantaneous snapshot of the waves coming from the slits. Equidistant from both slits, the waves interfere constructively-but the wave pattern oscillates up and down with time, of course. Keeping the strips taut, slide them over one another to the point where destructive interference occurs - the peak of one and the trough of the other coincide - the path lengths here differ by half a wavelength. Quantitatively - relate the horizontal distance the strips must be moved to go from one region of constructive interference, to the next, X say, with the separation of the slits d, the distance to the slits D, and the wavelength λ (two sets of waves can be made of differing wavelength).

$$X = \frac{\lambda D}{d}$$

1) R. A. Lohsen, Physics Teacher 21, 532 (1983).

5.05


CUT A DECKLE WITH HALF A SINE WAVE SO
FOLD PAPER STRIP - AS FOR MAKING PAPER DOLLS

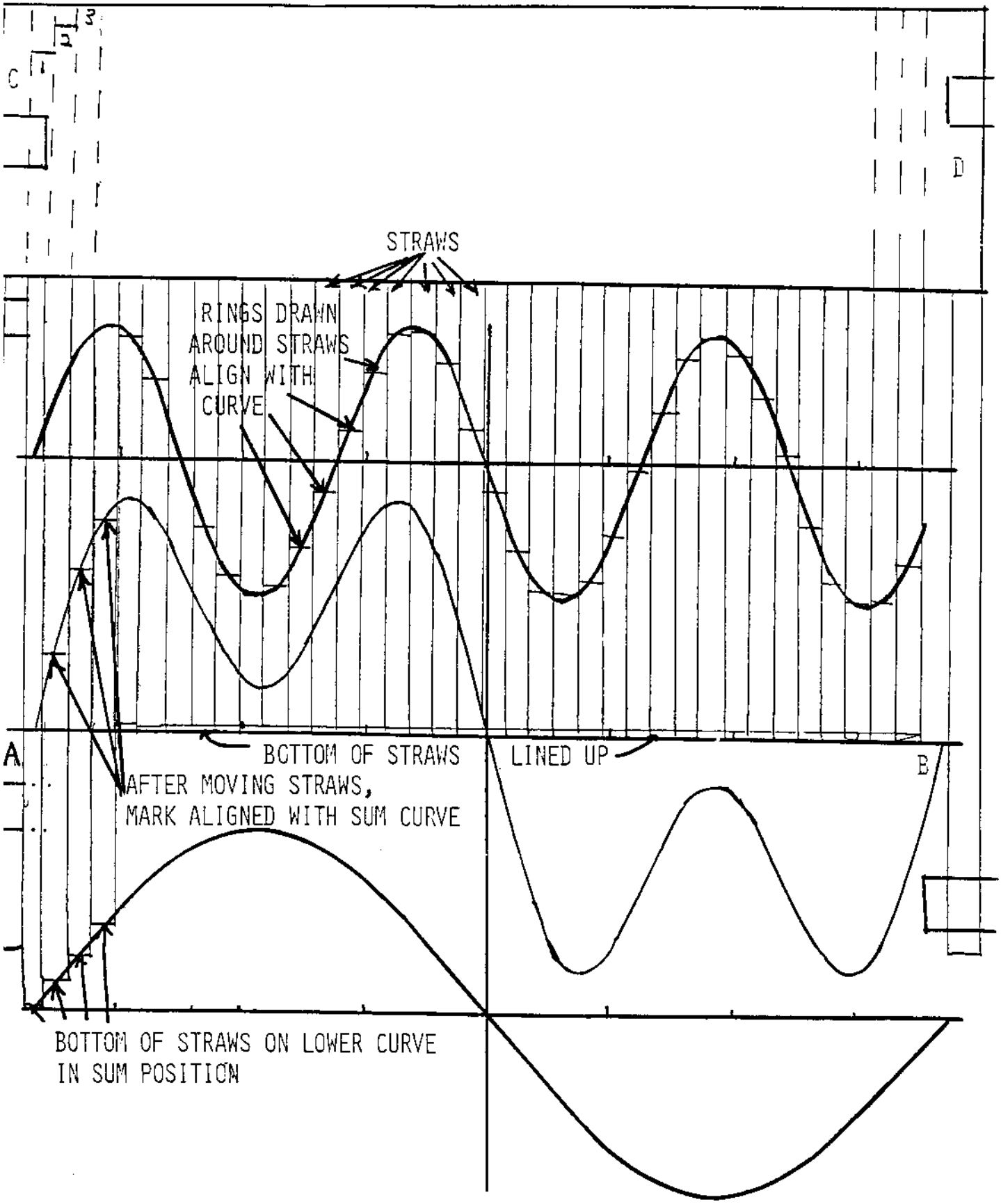

DRAW "SLITS" ON THE BLACKBOARD
d
ATTACH PAPER STRIPS
λ
D
POINT WHERE SCREEN WOULD BE PLACED
X

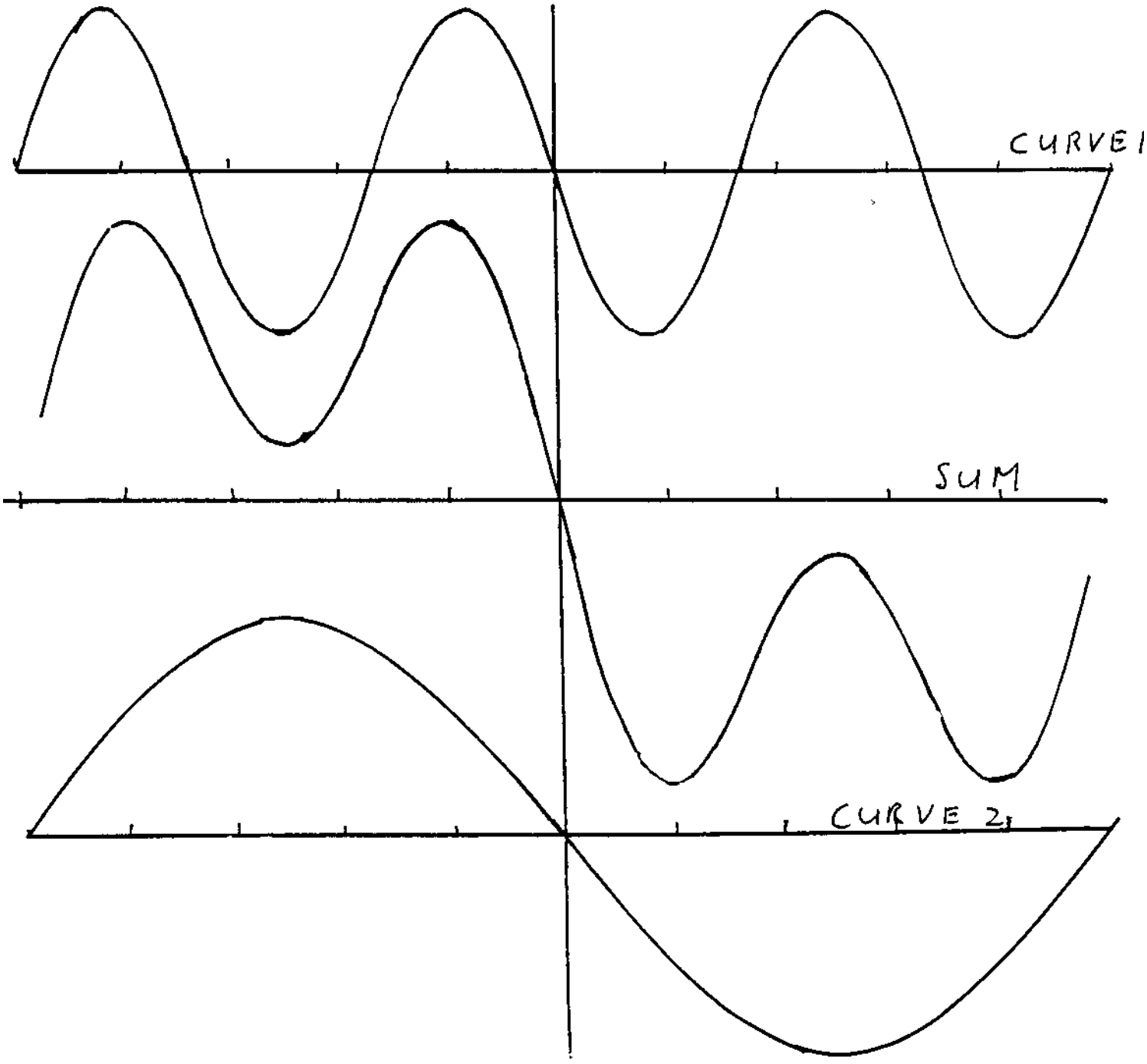
Experiment 5.06 Adding Oscillations

Music students forced (generally unwillingly) to take their first course in physics (often musical acoustics) have great difficulty understanding what is meant by the superposition - "adding" - of two simple harmonic motions - vibrations - at a point (as the effect on the ear drum of two tuning forks of different frequency). To help them picture what occurs, a simple device employing drinking straws, cardboard and tape can be used.

Figure 1 shows three time-displacement curves. Glue or tape this to a piece of card. The middle curve is the sum of the other two. To see, graphically, how this summation occurs, translucent drinking straws are lined up parallel as shown. The two end straws are taped to the back card, on either side of the bunch of straws, which may easily slide up and down between them. The bottom of the straws are aligned along AB using a ruler or you can tape a strip of card along the top, so that when the straws push against it, they are aligned along AB. A strip of stiff card, CD, is taped at the ends over the straws to prevent them crossing over one another. It is a good idea to fold the card as shown, and also the top of the back card, to provide the necessary rigidity so the straws do not cross over. A line is drawn around each straw with a suitable pen (felt tip, fiber etc.) where that straw passes over the top curve. The straws may be numbered at the top end in case they get shifted. The straws can then be slid down so their lower ends touch the bottom curve, and the marks around each straw will now follow the center curve, since we have added the length of straw between the bottom of the straw and the mark, to the bottom curve. Students unfamiliar with mathematics can follow this graphical act of addition much more clearly this way then by a written equation.

FOLD DOWN HERE

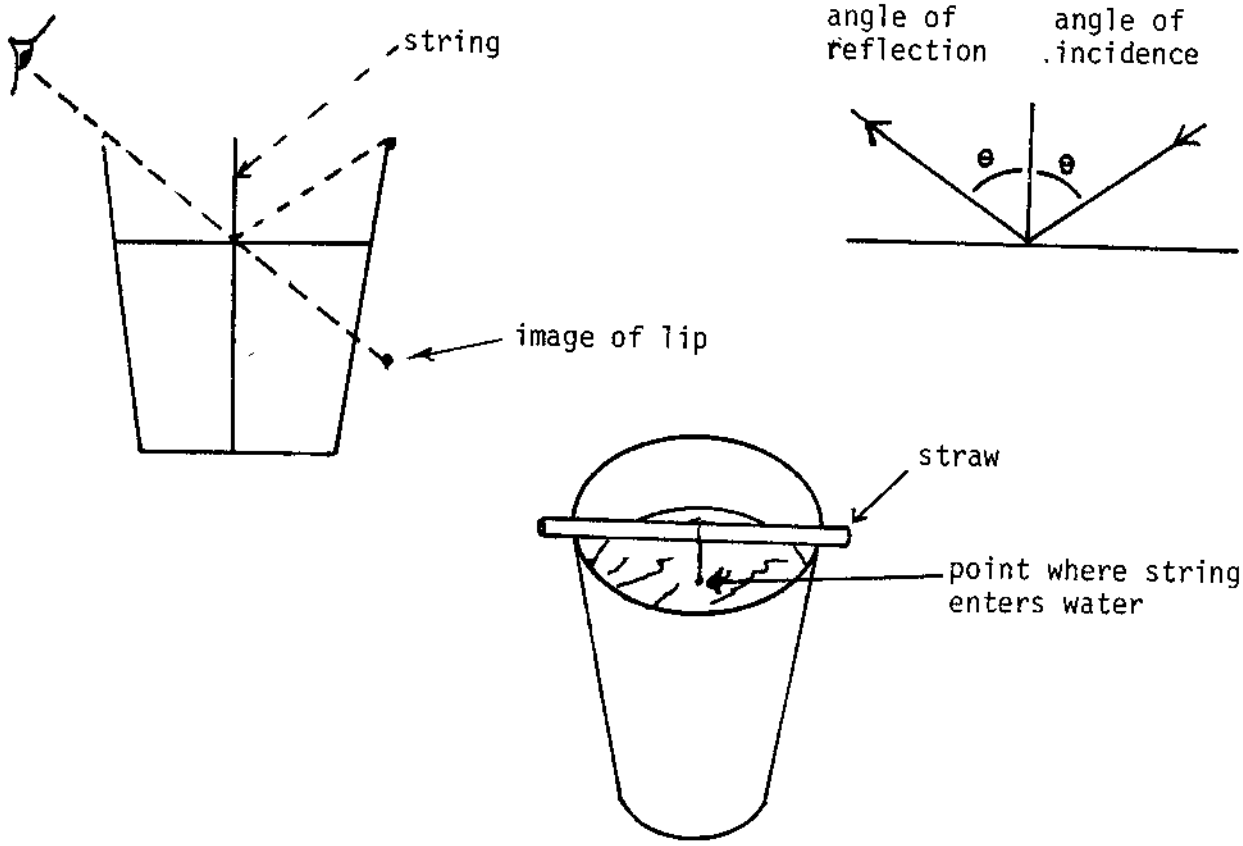



CURVE 1
SUM
CURVE 2

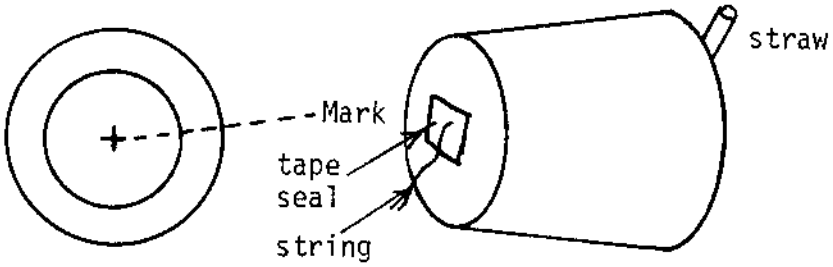
Experiment 6.01 Reflection of Light

Materials: -Foam or paper cups, string, sticky tape, soda straws

Instructions: -



Make a mark, as close to the center of the cup on the inside of the bottom as possible.



Make a small hole, tie the string around the center of the straw and pass the string through the hole from the inside, pulling taut and taping over the bottom, so water will not leak out. Adjust the straw so that the string is exactly vertical. Now pour a little water in the cup, and look at the reflection of the far lip. Lower your eye until the

reflection of the far lip is exactly on the rear lip. See if the string enters the water at this point. Examining the figure, you can see that if this is so, by symmetry, the angle of incidence on the water is equal to the angle of reflection. You can tilt the cup a little to adjust until where the string enters the water does lie exactly on the near lip, and the reflection the far lip. Now, pour in some water, and repeat the experiment. This increases the angle of incidence. Repeat for several angles of incidence.

Qualitative Questions: - What does this show about the reflection of light?

Quantitative Questions: - With what accuracy have you shown the angle of incidence is equal to the angle of reflection? (estimate this from the tilt you gave the cup) 10%? 1%? or 1/10%?

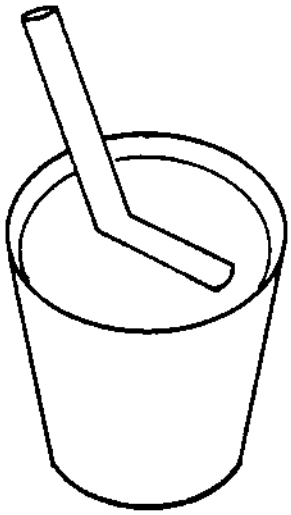
Note:- it is a good idea to illuminate the string, and employ a dark background

Experiment 6.02 Refractive Index of Water

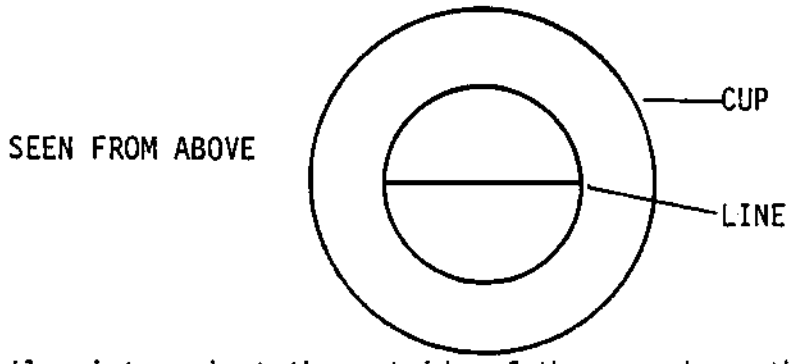
Materials - cup (as deep as possible), pencil, ruler

Procedure -

Qualitative - Place a pencil in water in the cup. Notice it appears bent as it enters the water. This is because the light travels more slowly in the water, and rays of light are bent as they leave the water surface.

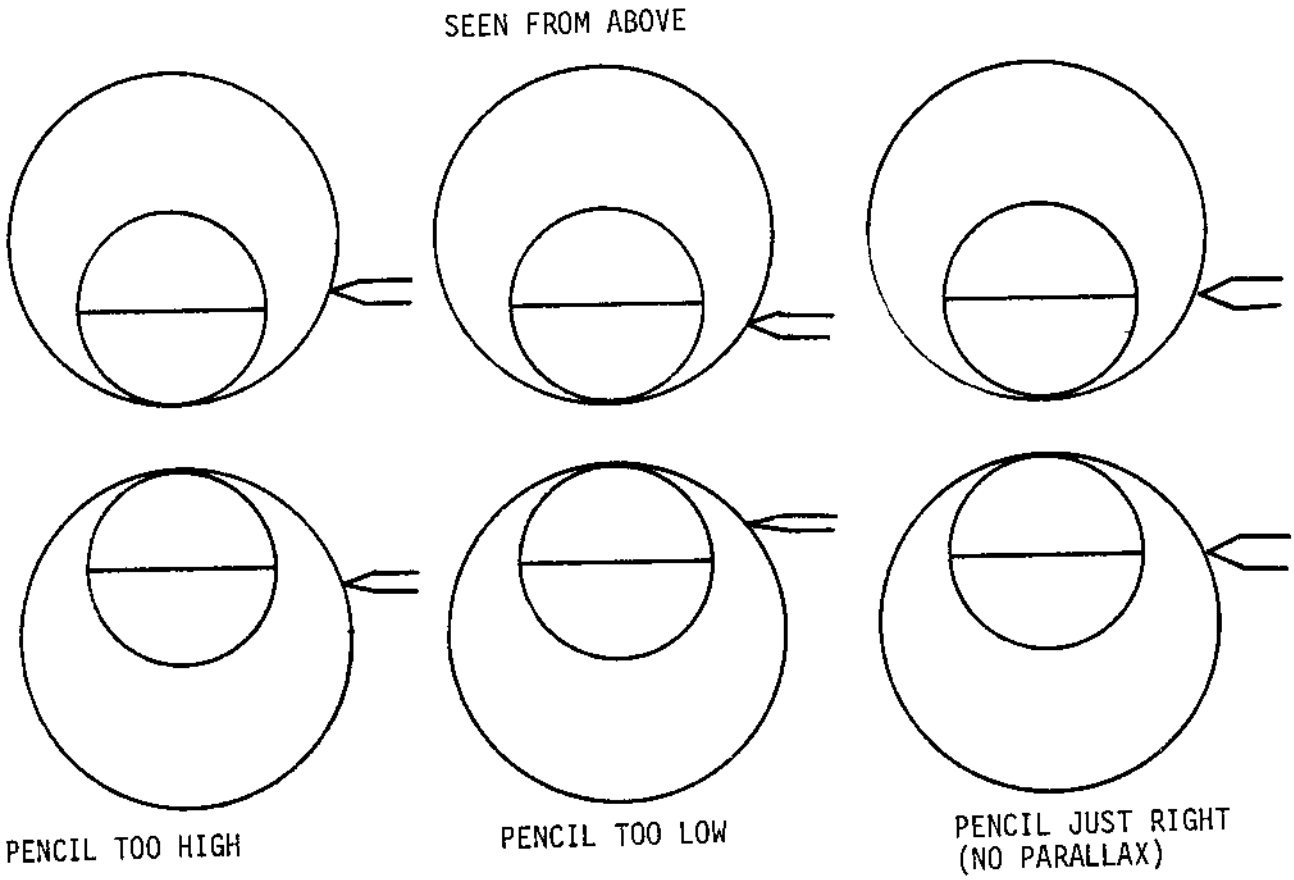


Quantitative : Draw a line straight across the middle of the dixie cup inside. Fill the cup to the brim with water.



Place a pencil point against the outside of the cup where the line appears to be and move the head up and down. Adjust the pencil until it is at the apparent depth of the line.

Make a mark on the side of the cup. Measure the distance from the lip to the mark, and to the bottom where the line was drawn.



What we learn

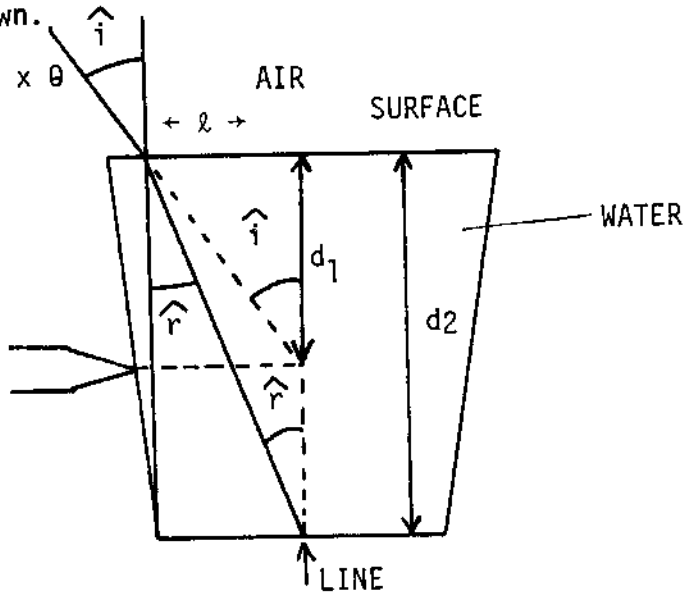
The refractive index is the ratio of the sine of the angle of incidence to the angle of refraction. For small angles, this becomes the ratio of the angles, as shown.

Using arc = radius x θ

$\hat{i} \sim \frac{\ell}{d_1}$

$\hat{r} \sim \frac{\ell}{d_2}$

$\frac{\hat{i}}{\hat{r}} = \frac{d_2}{d_1} = \mu$

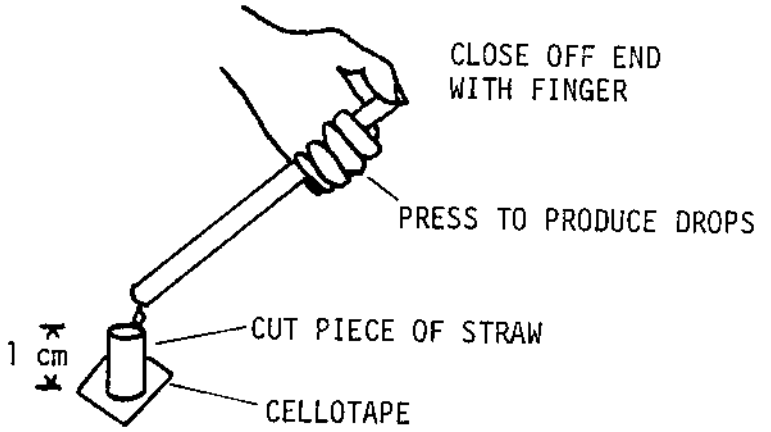


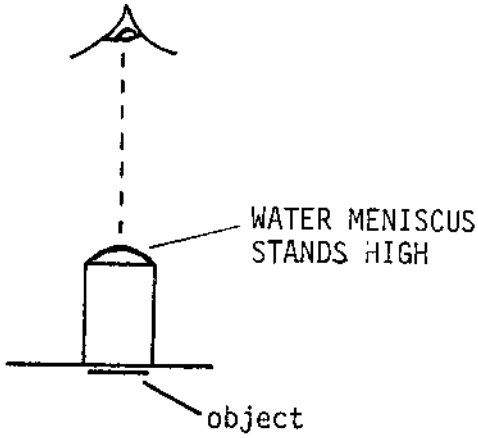
Hence, the ratio of the depth from the brim to the line drawn in the cup, to the depth of the pencil, is equal to the refractive index, which is 4/3 for water.

Experiment 6.03 Optics - Positive and Negative Lenses

Materials sticky tape (clear), soda straw, water

Procedure - Stick a piece of transparent tape flat over the end of a straw and cut a piece 1 cm (about 1/2 inch) long from that end. Place the tape over some object - a fly, or a printed letter - and fill the piece of soda straw, using the longer piece sucked full of water.



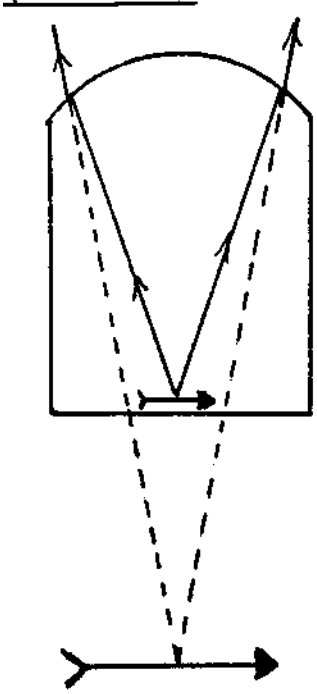


Make sure the meniscus stands high on the straw. Now, look down through the straw. You will see a magnified image of the object underneath. As the water leaks out of the bottom (or, you can soak up a little with toilet paper) the meniscus changes shape. When it stands high, we say it is convex. Hence, a convex lens can magnify in the same way as a magnifying glass, producing an image larger than the object. As the water leaks out, the surface caves in, and we say it is concave. Look at the object through the water now, and you see it appears much reduced in size like looking through the wrong end of a pair of binoculars. Concave lenses therefore give an image reduced in size. What do we learn?

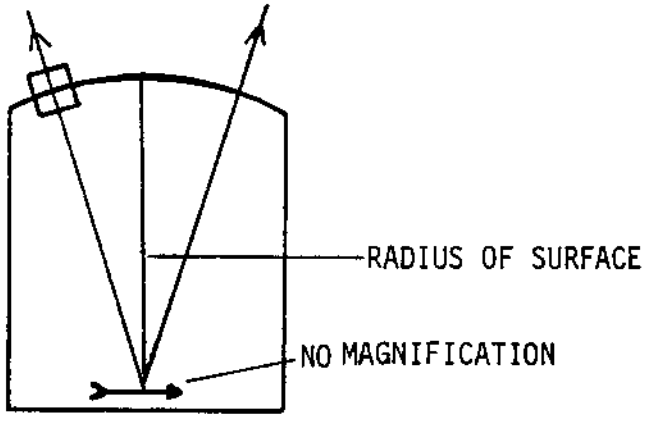
Qualitative - Convex lenses (bowed out) magnify

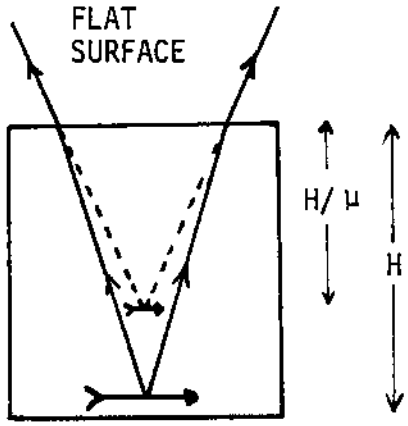
Concave lenses (bowed in) give images reduced in size

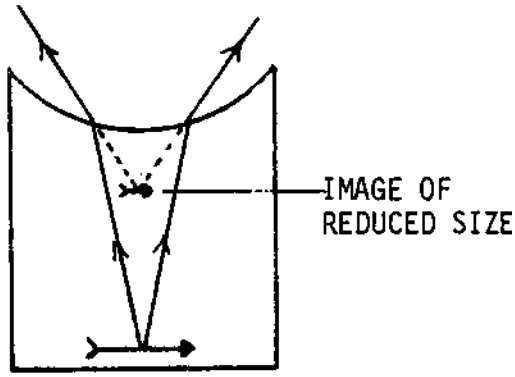
Quantitative - The ray trace of the system is shown below



LARGE VIRTUAL IMAGE





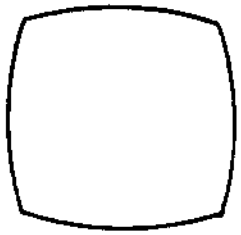


μ - the refractive index. the ratio of the speed of light in air to that in the medium.

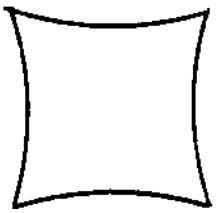
Look at the little square below through the water lens. When the meniscus is

convex

it looks like



This is known as barrel distortion, because the square image is distorted to look like a barrel. Distortion of this kind occurs with all lenses having spherical surfaces, such as this. When the lens becomes concave, the distortion changes and becomes pincushion distortion, so



Experiment - 6.04 Real Images

Materials - As for previous experiment, straw, water

Procedure - Take the water lens from the previous experiment, and fill it until the surface is convex (bulges out). Now, hold the lens vertically under the room light, a few inches above a sheet of paper. Move the lens up and down until you get an image or picture of the light on the sheet of paper. Because it actually lies on the paper, this is called a real image. The image is distinct, but not very clear. Notice as water leaks out, (or if you soak up a little on toilet paper) the image gets farther away from the lens. We say the focal length (the distance from the lens where a point very far away focuses) is increasing. Notice also that, as this occurs, the image gets bigger.

What we learn

A convex lens can form a real image, as shown — In the case of our water lens, where the bottom surface is flat, we can calculate the radius of the top surface from the formula for a thin lens-

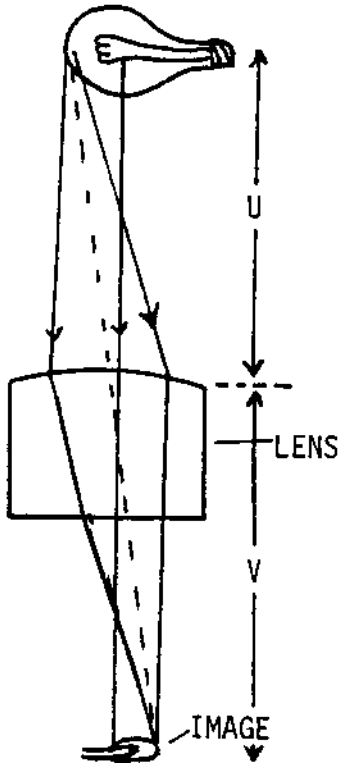
$$\frac{1}{u} + \frac{1}{v} = (\mu - 1)\frac{1}{r}$$

where μ = refractive index of water = 1.33

u = distance of object from lens

v = distance of image from lens

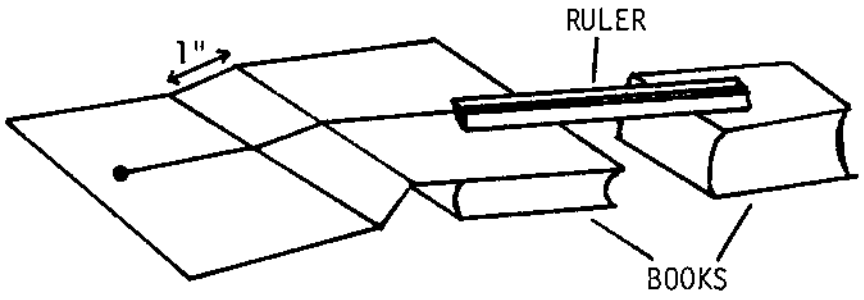
r = radius of curvature of the water surface



EXPERIMENT 6.05 Refraction of Particles

Materials: Chalk dust, cardboard, marble, ruler, protractor (from expt. 2)

Method: Fold about 1" down the middle of the sheet of cardboard, as shown, and place the top part on a book. Dust chalk over the surface.



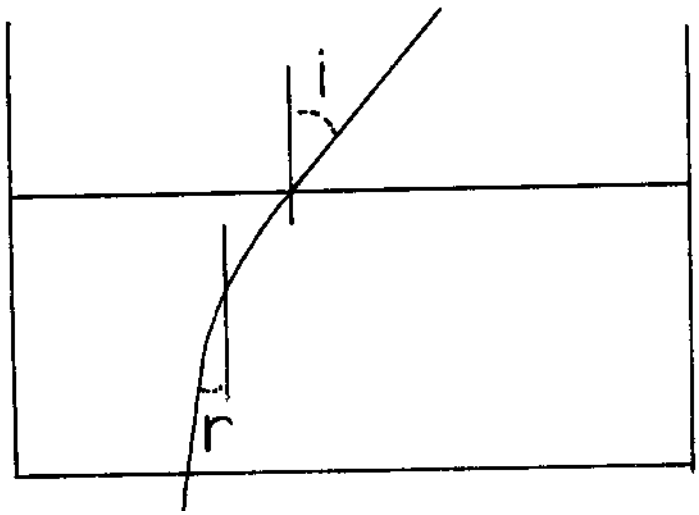
Now roll the marble over the dust, down the ruler, from the same height, but in different directions.

Qualitative: Does the particle bend in the same way light would in going from air to water? Do you think light could be a particle, like the marble?

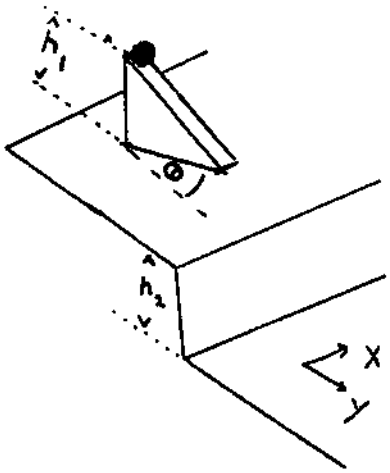
Quantitative: Snell's law states

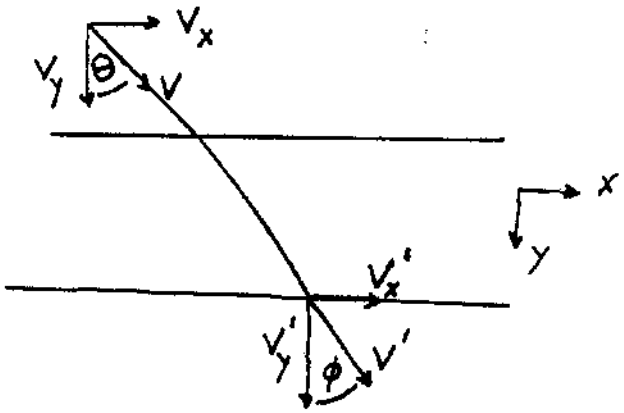
$$\frac{\sin i}{\sin r} = \text{const.}$$

Is this true for the trajectory of the marble?



To see how the trajectory of the marble compares with the path of a light ray, let us set the ball free down its shute from a height h, above the upper plane, and let the upper plane be a distance h_2 above the lower plane, as shown.





Using conservation of energy, as the ball rolls from one plane to the other

$$\frac{1}{2} mV'^2 = \frac{1}{2} mV^2 + mgh_2$$

$$V'^2 = V^2 + 2\,gh_2$$

We may divide this equation by V_x^2

$$\frac{V'^2}{V_x^2} = \frac{V^2}{V_x^2} + \frac{2gh_2}{V_x^2}$$

Since there is no acceleration in the x direction, $V_x = V_x'$,

$$\frac{V'^2}{V_x'^2} = \frac{V'^2}{V_x^2} = \frac{V^2}{V_x^2} + \frac{2gh}{V_x^2}$$

Now, $\sin\theta = \frac{V_x}{V}$, $\sin\phi = \frac{V_x'}{V'}$

so $\frac{1}{\sin^2\phi} = \frac{1}{\sin^2\theta} + \frac{2gh}{V_x^2}$

multiplying by $\sin^2\theta$

$$\frac{\sin^2\theta}{\sin^2\phi} = 1 + \frac{2gh}{V_x^2}\sin^2\theta = 1 + \frac{2gh}{V^2}$$

For light, the refractive index μ is given by Snell's law to be

$$\mu = \frac{\sin\theta}{\sin\phi}$$

But $\frac{\sin\theta}{\sin\phi} = \sqrt{1 + \frac{2gh}{V^2}}$ for our marble

Also, we have, since the marble rolled down a shute from height h_1, that $mgh_1 = \frac{1}{2}mV^2$

$$\frac{\sin\theta}{\sin\phi} = \sqrt{1 + \frac{h_2}{h_1}}$$

If we make $h_2 = 1.25\ h_1$, then

$$\frac{\sin\theta}{\sin\phi} = 1.5,$$ the refractive index for glass,

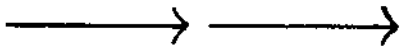
so the trajectory of the marble should follow the path of a light ray entering a glass surface.

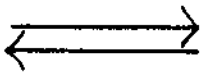
EXPERIMENT 6.06 The Phase amplitude diagram for a 12 slit interferometer.

Materials: Soda straws, string.

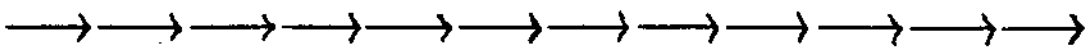
Procedure: It is frequently difficult to visualize the "curling up" of the phase amplitude diagram in diffraction. This provides a model which helps to demonstrate it.

We may represent the light passing through a narrow slit by a vector which is a straight line, and the phase of this vector relative to that of light passing through a second slit by the angle these two lines make. Thus, for two slits in a Young's interference experiment, if the light at a distant screen from one slit is in phase with that from the other, we represent it

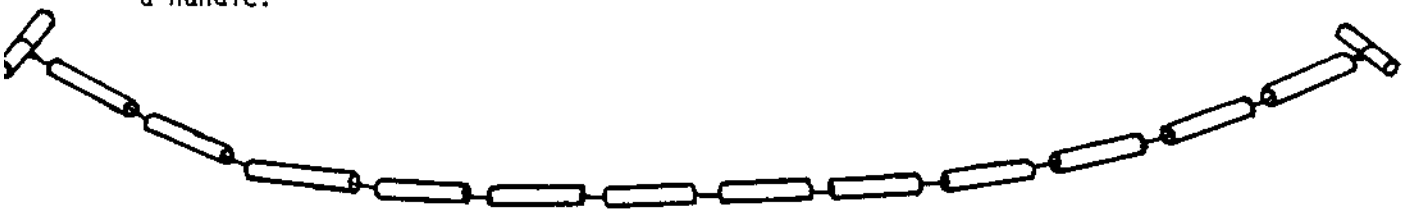
 and we get a maximum.

If out of phase  and darkness ensues.

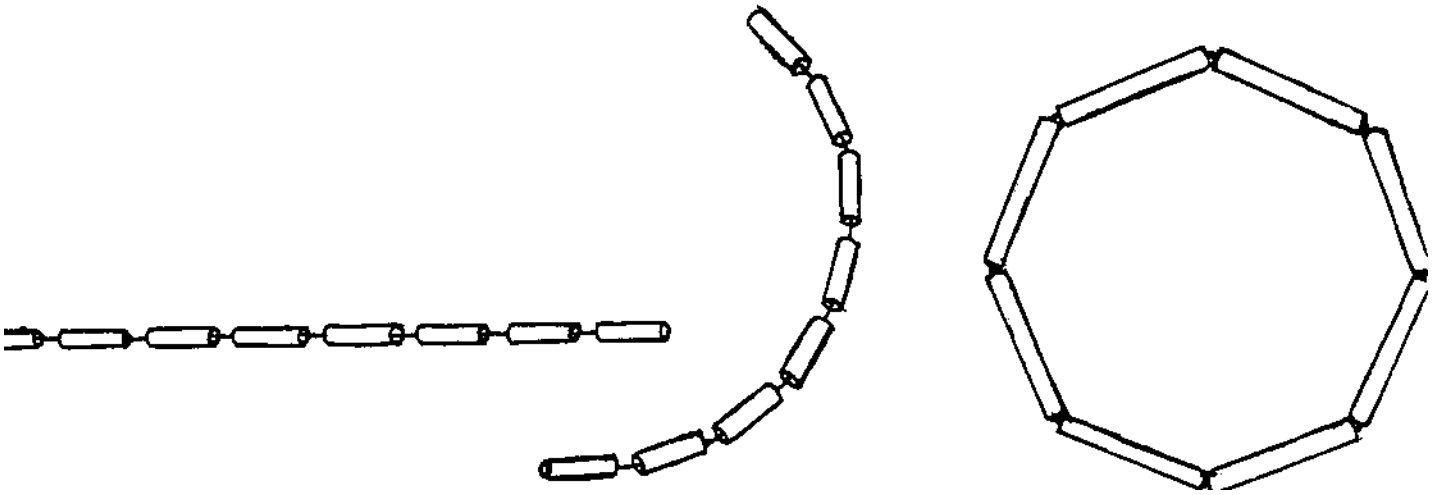
Extending this to twelve slits, equally spaced, we can represent them by twelve straight lines of equal length, which, when in phase appears



String 12 straws together as shown, attaching half a straw at each end as a handle.



We use each straw to represent the electromagnetic vector coming from one slit. When laid out in a line, the distance between handles represents the sum of the vectors with all the slits in phase. Pick up one handle; the vectors make roughly constant angles, and the closing vector gets shorter. Ultimately it will close on itself,



light, because it has a longer wavelength, and, in fact

$$\text{angle of first minimum} = \frac{\text{wavelength of light}}{\text{diameter of slit}}$$

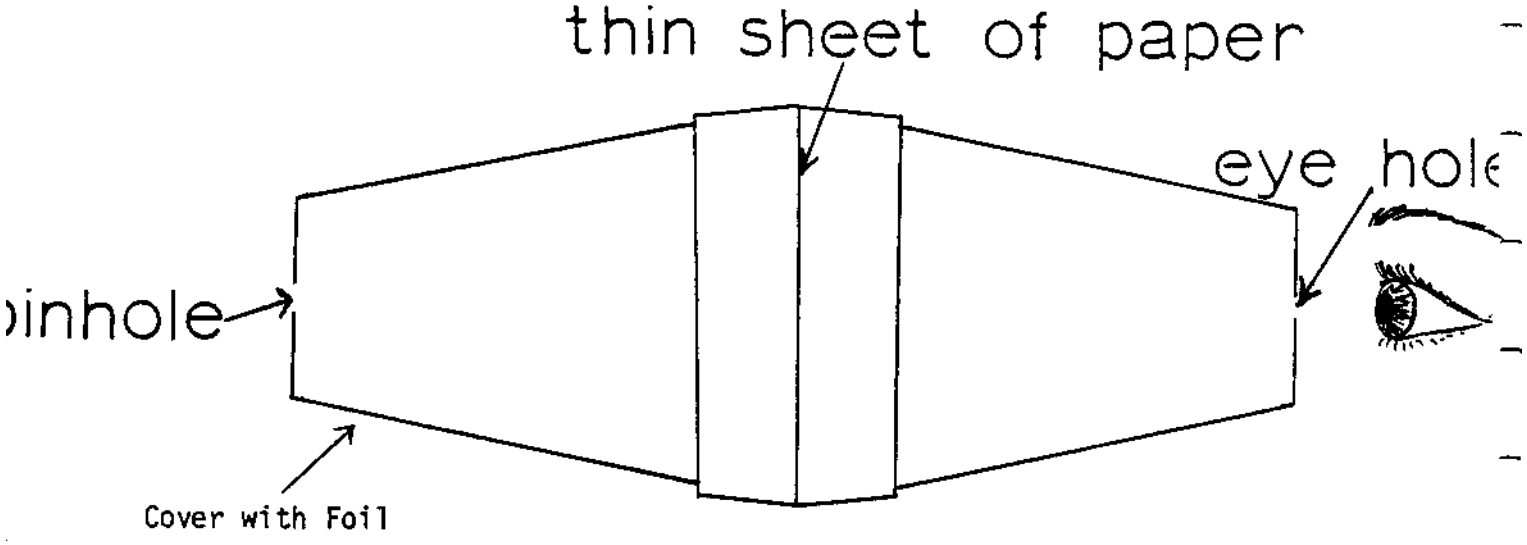
This type of diffraction occurs also in sound. Long waves bend more readily than short waves. This may be noticed by listening to music outside an open door not in direct line with the performer. The bass notes sound louder, since they bend more.

Experiment 6.08 Pinhole Camera

Materials: Two cups, tape, thin paper, aluminum foil

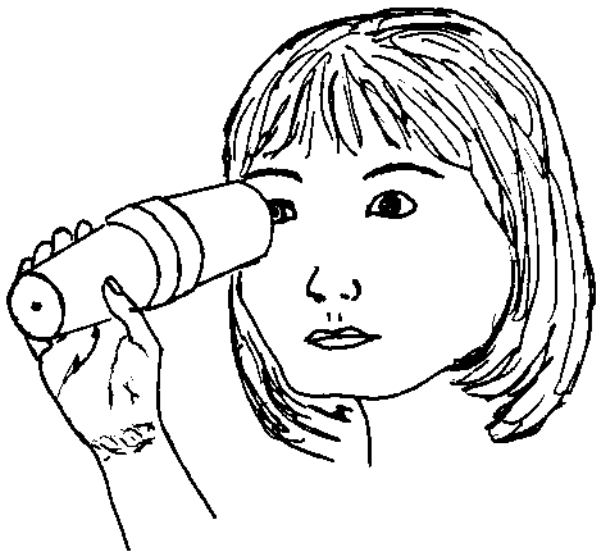
Procedure: Punch a hole with a pencil in the bottom of one cup, and cut a hole about an inch in diameter in the bottom of the other as the eyehole. Tape a sheet of paper over one cup, and attach the other, as shown.

Now, cover the whole of the two cups apart from the eyehole with one sheet of aluminum foil (such as Reynold's Wrap). The pinhole is made with a paper clip in the foil over the front cup. If aluminum foil is not available, make the pinhole in the front cup, then render the two cups opaque with black ink, or a dark cloth.

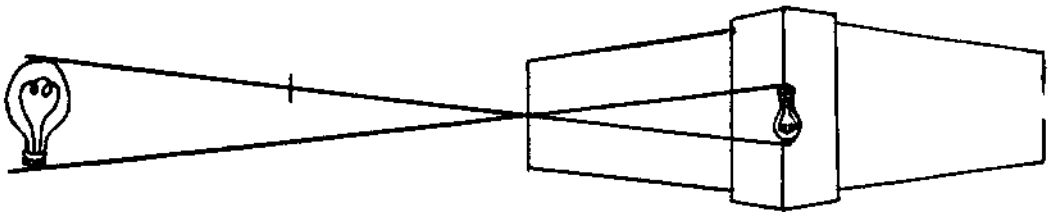


Pinhole viewer

Holding the cups up, an image is projected on the paper by the pinhole, and may be observed through the peep hole.



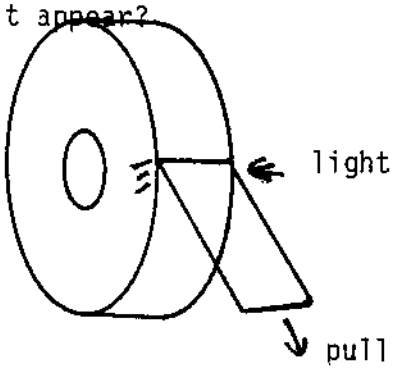
Widen the pin hole. What happens to the definition (sharpness) of the image? Is the image brighter? The image of an incandescent lamp, or other light is easiest to observe. What is the relationship of the size of the image to the size of the object? Is the image erect or inverted?



Experiment 6.09 Triboluminescence

Materials: Sticky, cellulose tape.

Take a roll of the tape into a very dark room. Rapidly pull a little off the roll. Where the tape pulls off the reel, light is given out. However, it is a weak source, and for such sources, the outer regions of the eye are more sensitive, so do not look directly at the roll, but about a foot or two away from it. What color does it appear?



Qualitative: This effect is known as "triboluminescence" see "The Flying Circus of Physics" 6.11 *

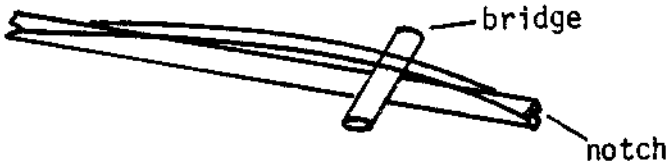
The bluish color arises because the rods of the eye are more sensitive to blue light, so all dim illumination appears bluish, since the rods are very sensitive to weak light.

* The Flying Circus of Physics. - Jearl Walker (Wiley 1977-)

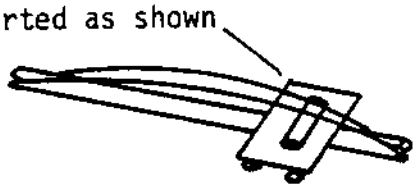
Experiment 7.01 The Rubber Band Guitar

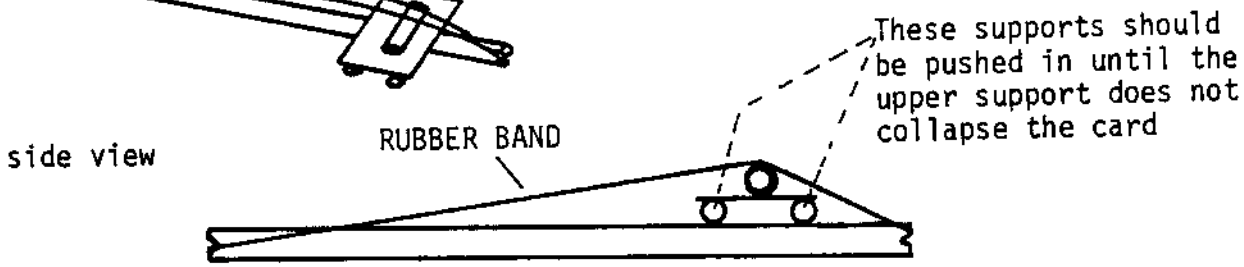
Materials: - soda straw, rubber band, cardboard

Instructions: - stretch the rubber band over the straw as shown (the ends of the straw may be notched). A small piece of straw acts as a bridge. A piece of cardboard



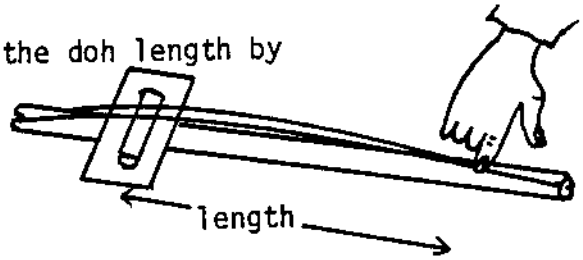
may be inserted as shown





Does the guitar sound louder with or without the card in place?

Starting with the open band as "doh", place your finger on the band to shorten it, and mark on the straw the position of the notes of the octave. Are they equally spaced? Measure the distance of the marks from the bridge. Now divide the doh length by



the ra length, the ra by the mi, and so on. Tighten the rubber band a little. Does the pitch go up or down?

Note: If you stretch a rubber band between your fingers and pluck it, it may go up or down in frequency, or even stay the same, as it is stretched. Think how the frequency depends on length, tension, and mass per unit length of the string to explain why this is.

Qualitative: - You have seen how the pitch of a plucked string depends on its length. How much shorter must a string be to give the octave? The pitch also depends on the tension on the string.

Quantitative: - The ratio of lengths, for successive notes, starting with do, should be ·89, ·89, ·95, ·89, ·89, ·95.

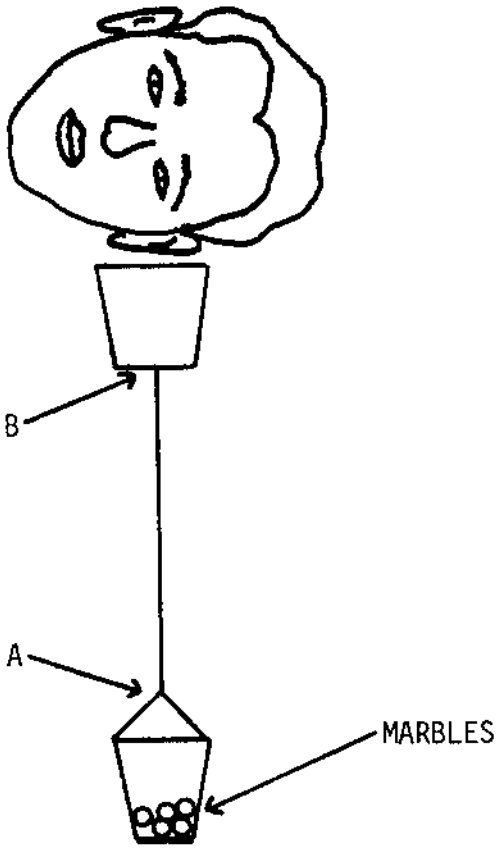
You will find this also on the guitar, notice that the big gaps are where the semitones (black keys on a piano) fit in. If you put in the semitone, the ratio is always ·95 (17/18) between successive notes, leading to a ratio of 2 for the octave.

Arrange the bridge half way along the string. The two halves give the same notes (unison). When the ratio is 2:1, the octave is heard 3:2, the fifth and 4:3 the fourth. Such ratios are pleasing to the ear, and called consonants. Pythagoreans thought these ratios had a mystical significance.

Experiment 7.02 The Way the Tension and Length of a Plucked String Affect its Pitch.

Materials: Two styrofoam (or paper) cups, string, marbles and a ruler.

Procedure: Hang one cup from the string, as shown, passing the string through holes poked in the top on opposite sides, and pass the other end of the string through a small hole poked in the bottom of the other cup. Tie small knots in the string 15 cm. , 30 cm. , and 60 cm. from A. Put ten marbles in the cup and pluck the string. Hold your ear over the cup, and



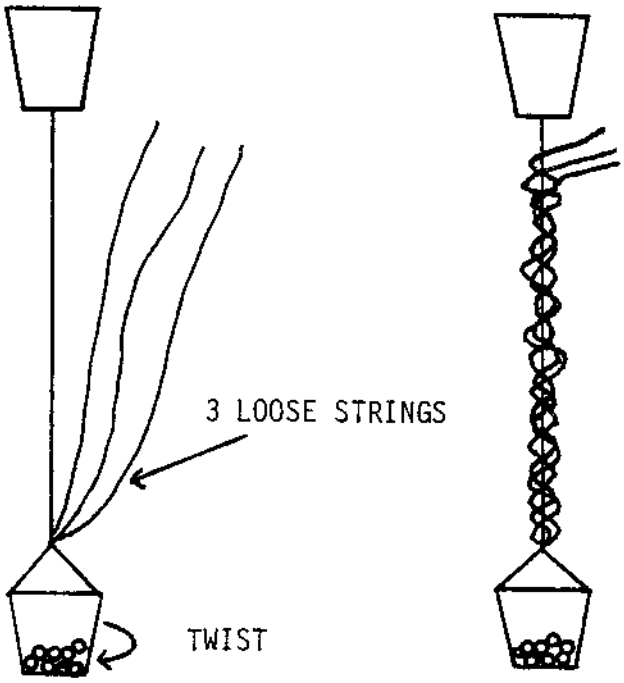
you will hear a clear tone, the string vibrating between A and B. Now, pull the string up until the 15 cm.knot is at B, and pluck again, noting the pitch. Drop to the 30 cm. knot and pluck again, and the 60 cm. knot. Does the pitch drop an octave in each case? If it does, the frequency also drops by a factor of two each time, since it is known, and we must assume that a note an octave higher than a second note, has twice its frequency. Depending on the length of the string you use, a clearer tone may be heard using more marbles.

Now set the string at the 30 cm. knot and pluck it. Add ten more marbles, and drop the string until it gives the same pitch as before. Measure the new length of string from A to B, using the ruler. You can go up and down, adding and taking away ten marbles until you get it right. What is the new length? Is it twice the old length? No, it is much less, showing that if you double the tension, the frequency goes up less than twice. In fact, the frequency should be proportional to the square root of the tension. Now, we doubled the tension by putting in twice as many marbles, so the length of string should be $\sqrt{2}$ larger. $\sqrt{2}$ is 1·412, so the new length should be 42.36 cm.

Find the length having the same pitch for 10, 15, 20 and 25 marbles in the cup. Put the numbers in the table below. Do they agree with the calculated values? If so, you have shown that the square root of the tension is proportional to the length of string for the same pitch, and we deduce that, if we keep the string the same length, the square root of the tension is proportional to the pitch. So we need not twice, but four times the tension to make the pitch increase a factor of two, i.e. an octave. Try this out by putting as many marbles as possible in the cup, and then reducing to one quarter. Does the pitch drop an octave?

Number of marbles	$\sqrt{\text{number}}$	3.16 x $\sqrt{\text{number}}$	Experimental length, cm.
10	3.1622	10	
15	3.8729	12.24	
20	4.472	14.142	
25	5	15.8	

What happens to the pitch with a thick string? Attach three strings to the top of the lower cup, with, say twenty marbles in. Pluck the string. Now, spin the lower cup. The three loose strings will wind around the one taut one, so



it is four times as heavy--the mass per unit length is four times as great. Again pluck the string. What happens to the pitch? Take out marbles until you have the same pitch as before.

Question: How many marbles must be removed? Is the pitch proportional to 1/(mass /unit length) or $\frac{1}{\sqrt{\text{mass/unit length}}}$

Theory shows that the frequency of the fundamental mode $f \propto \frac{1}{L}\sqrt{\frac{T}{m}}$

where m is the mass per unit length of the string, T is the tension in the string, and L is its length.

Experiment 7.03 Waves in Pipes

Materials: Soda Straws

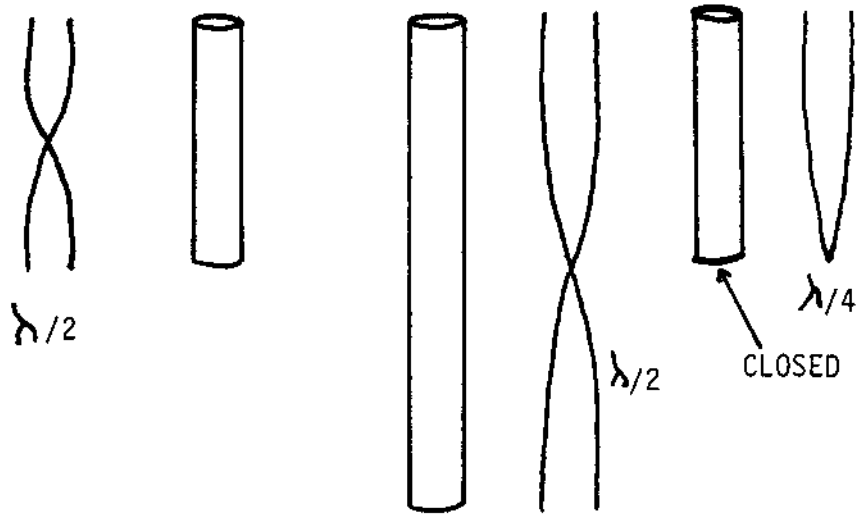
Procedure: Take two straws. Cut one in half. Blow across the end of each tube. How does the pitch of the longer tube compare with the shorter.

1. Does the pitch go up or down with the length?
2. Is a pitch change of an octave or a fifth given by a length of a factor of two?

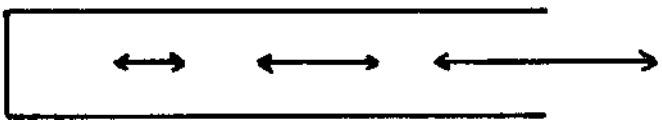
Close the bottom end of the smaller tube with one finger, and again blow across the top end.

3. Does closing a pipe raise or lower its pitch?
4. Does its pitch change by an octave? Is its pitch the same as an open pipe twice the length?

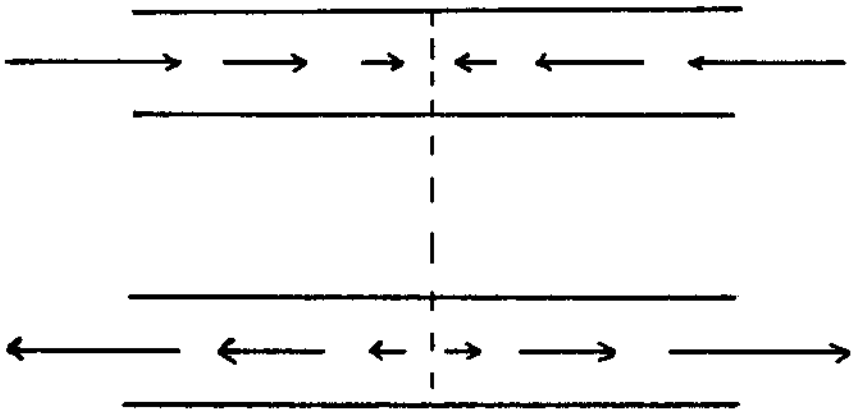
Why is this?



The closed tube has a node at one end, and its fundamental mode is one quarter of a wavelength long. In this mode, air rushes in and out of the open end, the



motion diminishing until at the closed end it is zero. The open tube has a node at the center, and is half a wavelength long.



NODE

Listen to the timbre of the closed pipe, half a straw long, and the open pipe, a whole straw long. They have the same pitch, but sound quite different. The open tube has all the harmonics, the closed tube only the odd harmonics.

To determine frequency threshold of hearing, cut a straw into shorter and shorter lengths until the frequency can no longer be heard on blowing across the top. The upper frequency is about 16,000 Hz, which is produced by a straw 1 cm. long, roughly half an inch.

Equal Temperament

The ratio of frequency for successive notes on the scale of equal temperament is a constant - 1.059, which is approximately $\frac{17}{18}$. To make a scale based on equal temperament using straws, the ratio of successive lengths should be $\frac{17}{18}$. Cut the straws:

8"*, 7.55", 7.13"*, 6.73", 6.35"*, 6"*, 5.66", 5.34"*, 5.04", 4.76"*, 4.49", 4.24"*, 4"

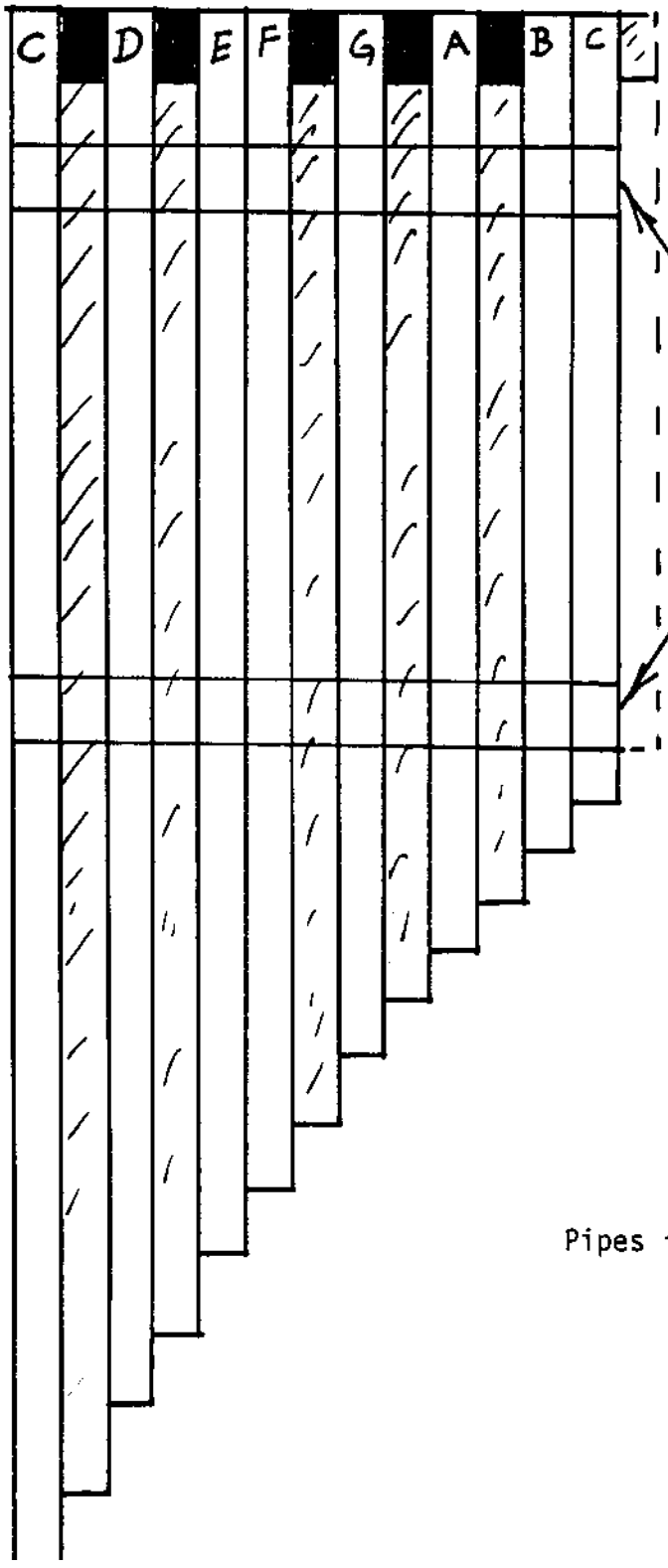
These will form a scale of equal temperament, those with asterisks forming the natural octave. Join them together with tape, to form pipes of Pan, as shown. The lengths are correct, as drawn and can be used to measure the straws.

Equal temperament never gives a chord having exact fifths, i.e. the ratio of two notes is never exactly 3/2. However, you can construct an octave of pipes according to the Greek Pythagorian scale, which does give exact fifths.

The straws should be cut to lengths in inches:

	8	7.111	6.32	6"	5.333	4.74	4.21	4
frequency ratio	1	9/8	81/64	4/3	3/2	27/16	243/128	2
interval		9/8	9/8	256/243	9/8	9/8	9/8	256/243

The perceptual differences between Pythagorean and equal temperament are small, but noticeable.



Blow across the top

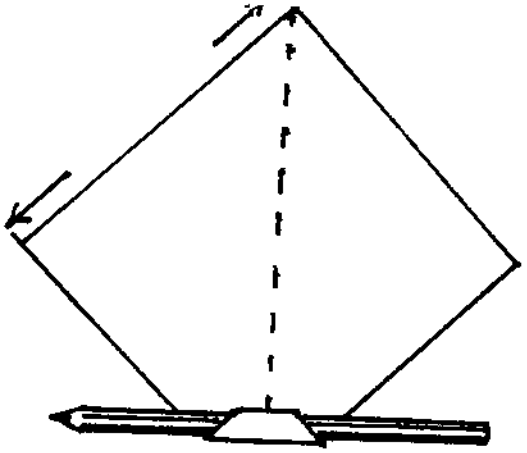
Tape both sides

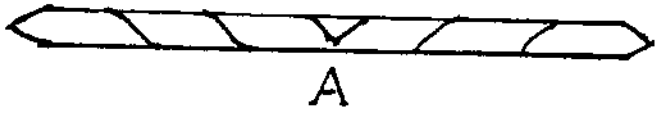
Pipes for Equal Temperament

Experiment 7.04 The Reed

Materials: paper scissors and tape

Procedure: Take a six to 8½ inch square of paper and fold along one diagonal. Then open out and proceed to roll the paper tightly around a pencil from one end of the diagonal crease to the other end, so that the diagonal rolls along itself as shown in the figure. If a six sided pencil is used, do not wrap too tightly, or the pencil will not come out. When completely rolled it should look like the lower figure. Push the pencil out and paste the last fold at A., or hold it in place with a rubber band or strip of tape The ends of the roll will look like the figure below.

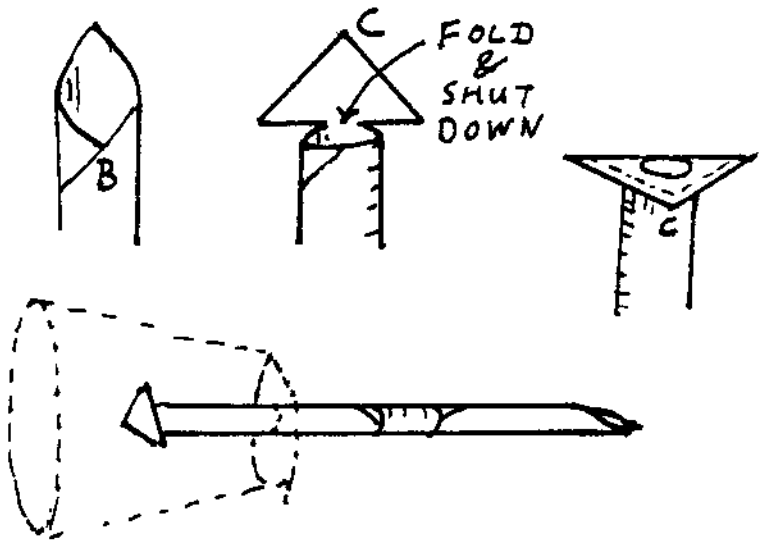




A

Now from point marked B. at one end cut away on each side, in direction indicated by the small arrows, until the end piece may be opened out into a triangle shape C. The cuts must be at right angles to the main roll and are each a trifle over one third of the circumference of the rolled tube. Now

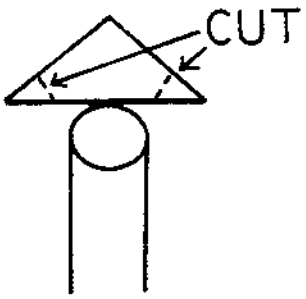
fold the triangle piece at right angles to the tube so that it forms a little cover over the end (see figure below). Trim away a small part of the triangle on each side along the dotted lines indicated in sketch, but do not trim too close. Now place the other end of the tube in your mouth, and, instead of blowing, draw in your breath. This action will cause the little triangular paper lid to vibrate and the instrument will give a bleating sound. The noise can be made louder by rolling a cornucopia or horn and putting on the tube as shown in the last figure, or the tube can be poked through a hole in the bottom of a styrofoam cup, to act in the same way.



Qualitative: How does the reed work?

This type of reed, in which the flap closes off the aperture completely, is known as a "beating reed", and is used in the clarinet, oboe and bassoon. The clarinet has one reed, and the oboe and bassoon two reeds beating together. The vocal cords are also similar.

A puff of air is allowed into the pipe each time the flap opens and closes, and such sharp puffs have a lot of high frequencies in them, in addition to the lowest frequency, or fundamental. Now, cut the corners off the reed, as shown



(Take care that the reed covers the tube--otherwise it will not work). Does the pitch go up or down? The natural frequency of vibration of the reed, (as with all simple harmonic motion) is higher the smaller the mass oscillating.

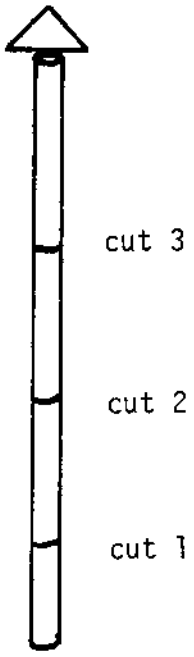
Why does putting the horn over the reed make it sound louder?

In a wind instrument, the reed is not free to vibrate at its natural frequency, as here, but is forced to oscillate at the resonant frequency of the tube of the instrument. The paper reed can only vibrate at a low frequency, so you would need a tube about three feet long to be able to bring the reed into resonance. If you have such a tube, you could try it out.

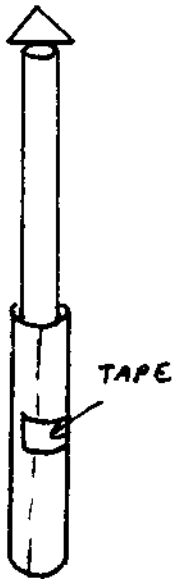
We can examine the way the voice works using this device. The foam cup over the end of the tube has its own resonant frequency. The vocal tract (larynx, mouth) behaves similarly in the case of the voice. The resonance is at a high frequency, and tends to emphasize frequencies produced by the reed in this vicinity--these resonant frequencies are called formants in the case of the voice, and determine whether you are saying "oo" or "ah", even if our voice holds the same basic fundamental pitch.

While sucking on the reed, close the cup partially with one hand, then open it again. Doing so alters the formants, and it is quite easy to get the device to say "ma ma" or even more difficult vowel sounds with a little practice.

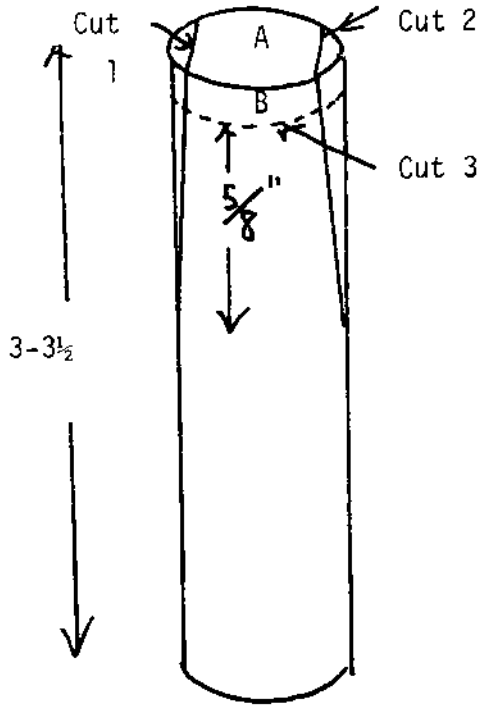
Try cutting the tube shorter, and shorter. Does the pitch of the reed change? At what length does the reed stop functioning? Clearly, the air in the tube is necessary to the functioning of the reed, even though the length does not determine the pitch in the same way as it does for an open pipe.

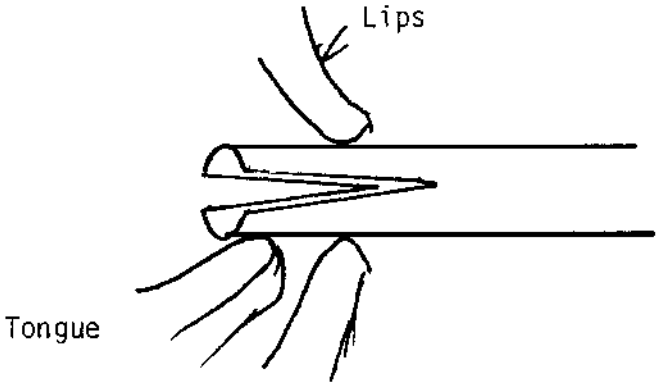


After cutting the reed shorter, around the outside roll a tube of paper and tape it as shown. Slide the outer tube up and down. Does the pitch go up or down as you slide the tube in and out? Why?



A reed can also be made from a plastic soda straw by cutting slits on either side at the end, as shown





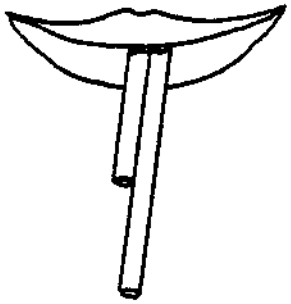
Place the reed in your mouth, and chew the flat ends A and B between your rear molars until they are quite flat and parallel.

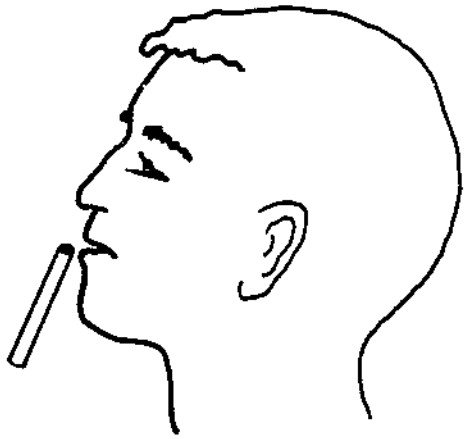
Some practice is required in blowing this. Roll the reed between the lips while blowing--the range of pressure under which you can make the reed sound is rather restricted. The top and bottom reeds should be closely the same size. This is similar to the double reed in an oboe, so you can insert it into a paper cone and see how it sounds.

Experiment 7.05 Combination Tones

Materials: - Soda straws

Instructions: - Cut one soda straw 5.0 cm. long, and one 6.7 cm. long. One has a pitch approximately 3300 and the other 2460 Hz. Now, blow them simultaneously as shown





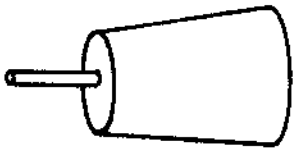
What do you hear?

Quantitative - in addition to the two tones, a third is heard. If you cut a soda straw 20 cm. long corresponding to the difference in frequency of the two straws, (840 Hz) it may help you to hear this different tone.

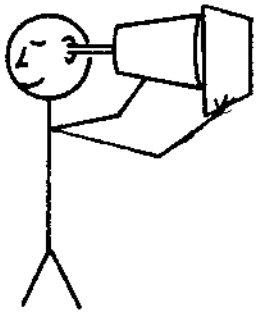
EXPERIMENT 7.06 Resonance in Sound

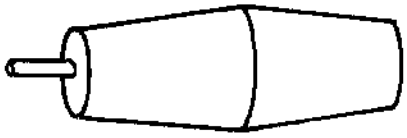
Materials: Two Styrofoam or paper cups, straw, sheet of card, sticky tape

Procedure: Poke a hole with a pencil in the bottom of the cup, and insert about two inches of straw, as shown



Attach it firmly by putting strips of tape around the junction. Now carefully insert the straw in your ear, and cover the mouth of the cup with a sheet of card.





Leave an opening for sound to get in as shown. You have probably, at some time or another, "listened to the sea" by holding a conch shell to your ear, and you will find you can hear the sea just as clearly with the cup as the shell. What is happening is that the cup resonates to a certain unique pitch or frequency. Just as the pendulum responds to oscillations of only one frequency, so the cup responds to only one pitch. So, of all the sounds in the room, you hear this pitch greatly exaggerated. To find which pitch this is, ask someone to sing or hum continuously from low to high. You will hear the resonant pitch stand out, sounding loud compared with the others. Now, the size of the cup determines the pitch, so take a second cup, and put it over the first instead of the card with enough gap between to let sound in (or you can poke a hole through the base). You will find it resonates at a lower frequency and, in fact, it will be about an octave lower, because you have twice the volume of container. You can also vary the resonant pitch by moving the card across the top. When the card covers most of the cup, the resonance is sharp, (i.e., that one pitch is much exaggerated, or amplified) as the card is moved back, the resonance pitch becomes less sharp, until, when completely removed, there is practically no resonance at all.

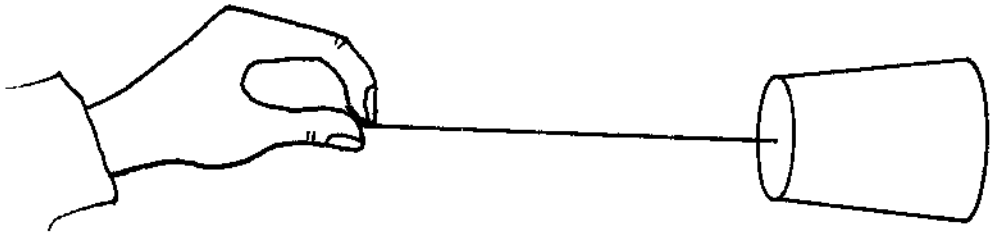
Qualitative questions: Why should a hollow container resonate in this way? Think about the way sound bounces around inside the cup, and the way, if you blow across the top of a bottle (or across the opening left when the card all but covers the cup) you get a note, which is the resonant frequency of the device--this can be used to find the resonant frequency of your cup-resonator instead of humming.

uantitative questions: The linear size of the cup is a fraction of the wavelength to which it resonates. Measure the size of the cup. The frequency times the wavelength is the velocity of sound, so to what frequency does the size correspond? The velocity of sound in air is 330 m. or 1100 ft. per second. Is the real frequency higher or lower than this? (Remember, middle C on a piano has a frequency of about 260 cycles per second, and when you blow across a straw 15 cm. long, open at both ends, it vibrates at 1100 cycles per second).

Experiment 7.07 The String Telephone

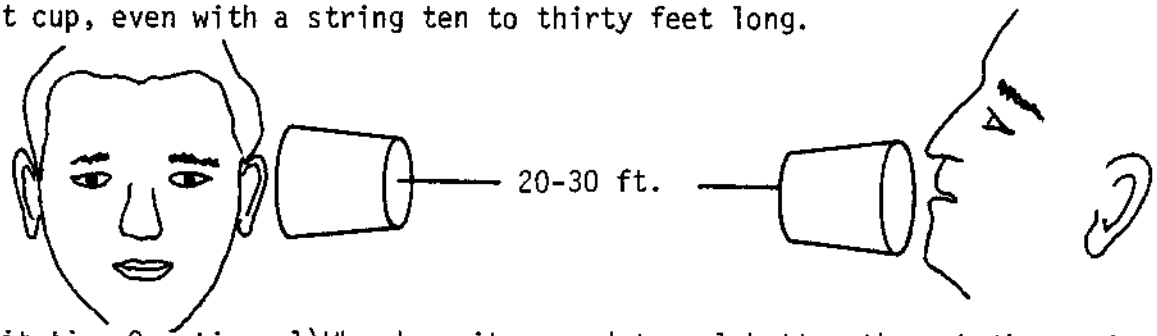
Materials: two styrofoam cups, string

Procedure: Tie a knot in a piece of string, and draw the string through a small hole in the bottom of a paper or styrofoam cup. Draw the string between the thumb and forefinger.



Qualitative Questions: Are the vibrations generated longitudinal or transverse? Why does the cup appear to amplify the sound? Does the pitch go up and down as you hold the string tighter, and put more tension on the string?

Now, push the end of the string through a small hole in the bottom of the second cup. When you talk into it, the speech is clearly audible in the first cup, even with a string ten to thirty feet long.



Qualitative Questions:1)Why does its sound travel better through the string than through the air?2)Are high or low frequencies transmitted better?)Does this depend on the tightness and density of the string and the size of the cup? 4) Approximately how much more energy reaches the hearer's ear with the cup than without it?

Flying circus of physics 1.9

EXPERIMENT 7.08 Acoustics of Rooms -- Reverberation Time

Materials: A watch, if available.

Procedure: Musicians often comment that a given hall is "live" or "dead". Physically, this is expressed as the reverberation time--the time taken for a loud sound, such as a pistol shot--to fall to the point where it is no longer audible. More accurately, the reverberation time is defined as the time taken for the energy density of sound in the room to fall by a factor of a million--a range of 60 dB.

Pick a suitable hall, or large room, and measure the reverberation time to see how long it takes for a loud sound--a sharp hand clap will do--to become inaudible. Time it with a watch or pendulum. Many students should repeat this many times, and an average taken. The reverberation time should now be calculated. First, we need to know the areas of different absorptive materials in the room. Each surface must have an absorption coefficient associated with it, depending on whether it is strongly absorptive or not. An open window is completely absorptive--nothing of what goes out the window ever gets back--so we may give this an absorption coefficient of unity. We can then say that other materials have some fraction of this -- for example, if we cover the window with plywood, it will absorb $\frac{1}{10}$ of the sound falling on it, that a window of the same size would let out, so its absorption coefficient is $\frac{1}{10}$ or 0.1. Then, the reverberation time would be ten times as long, and we have a new equation, replacing the opening area A by the sum of all the absorptive surfaces a_1, a_2, etc. multiplied by their absorption coefficients, S_1, S_2 etc. The absorption coefficient is the ratio of the intensities of the sound absorbed to that incident on the material.

$$A = S_1a_1 + S_2a_2 + S_3a_3$$

The unit of absorption, Sa, is called the Sabin after a famous acoustics expert. The values for these absorption coefficients are given in table 1. Notice how low frequency sounds are poorly absorbed. The values at 500 or 1000 Hz may be taken as an average since sounds in this range tend to dominate.

Having calculated the absorptive area A in square feet of open window in this fashion, we proceed to calculate the volume V of the room in cubic feet, by multiplying the height by the width by the length of the room. The reverberation time T is then given (approximately) by

$$T = .049\ V/A$$

We can see how this happens by looking at the curve of decay of sound in a room with an open window. In a time t_1, half the energy would have flowed out. It would take the same time again for half of what was left to flow out, and so on. This is an exponential decrease, the power escaping depends on and is proportional to the amount of energy remaining in the room. Now, the time it takes the sound to escape will clearly depend on the size of our open window--like a hole in a bucket, the bigger the opening, the faster the leakage, so the power escaping is proportional to the area, and the time it takes for a fixed amount of sound energy to escape is inversely proportional to the area,

so the time for this sound to escape $T \propto \frac{1}{A}$. Similarly, for a given noise level, the bigger the room, the more sound energy it contains, so the longer it takes to empty, hence

$T \propto V$ -- this is like saying it takes longer for a bigger bucket to empty through the same hole.

so $T \propto \frac{V}{A}$

where V is the volume of the room and A the area of the open window.

Now you can see, a hall with a short reverberation time is "dead" -- one with a longer time is more live -- but too long and you can't hear yourself speak. For example, rooms with completely reflecting walls having but one opening are uncommon. However, squash and handball courts closely approximate this. A squash court is 21 ft. by 32 ft. by 20 ft. high, giving a volume of 13,440 cubic ft. The opening in one wall (for spectators) is 4 ft. by 21 ft., an area of 84 sq. ft. This leads to a reverberation time of 7.84 sec. A handball court is 20 ft. by 40 ft. by 32 ft., with an opening 4 ft. by 20 ft, though the latter may vary.

How suitable is the reverberation time of the room you selected, for its purpose?

On the whole, reverberation times for lecture rooms, where speech is the principle use, should vary from 0.4 second for a small room to 0.8 seconds for large lecture theaters. Concert halls must have a longer reverberation time, from 1 to 1.2 seconds for chamber music, to 1.7 seconds for opera and orchestral concerts. It is clear from this why the words in opera are so difficult to distinguish--the acoustics of the opera house blurr them, because of the relatively long reverberation time. For organ music, written to be played in a vast cathedral, a reverberation time of two seconds or longer proves quite suitable.

The reverberation time should be longer for the deeper notes. This is accomplished by ensuring the absorptive properties of the auditorium are larger for the higher frequencies--which is generally true in any case.

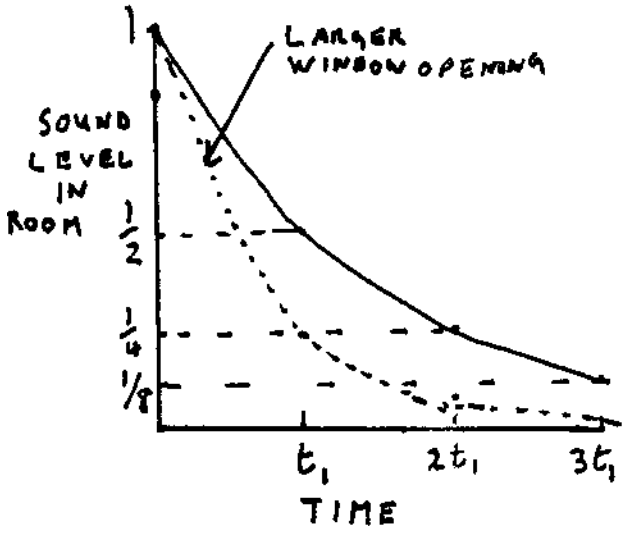


TABLE I

Absorption Coefficients of Some Building Materials

	FREQUENCY--CYCLES PER SECOND					
	125	250	500	1000	2000	4000
Marble or glazed tile	.01	.01	.01	.01	.02	.02
Concrete, unpainted	.01	.01	.01	.02	.02	.03
Asphalt tile on concrete	.02	.03	.03	.03	.03	.02
Heavy carpets on concrete	.02	.06	.14	.37	.60	.65
Heavy carpets on felt	.08	.27	.39	.34	.48	.63
Plate glass	.18	.06	.04	.03	.02	.02
Plaster on lath on studs	.30	.15	.10	.05	.04	.05
Acoustical plaster, 1"	.25	.45	.78	.92	.89	.87
Plywood on studs, 1/4"	.60	.30	.10	.09	.09	.09
Perforated cane fiber tile, cemented to concrete, 1/2" thick	.14	.20	.76	.79	.58	.37
Perforated cane fiber tile, cemented to concrete, 1" thick	.22	.47	.70	.77	.70	.48
Perforated cane fiber tile, 1" thick, in metal frame supports	.48	.67	.61	.68	.75	.50

Experiment 7.09 Velocity of Sound

The velocity of sound is generally measured by resonances in tubes, and other rather complex methods. The simplest method is probably to time an echo, but it is difficult to find a suitably distant cliff or canyon wall. Two people can combine to measure the speed of sound fairly accurately as follows. We can count easily about five hand claps a second. If the speed of sound is 330 m.(1100 ft.)/sec., and we stand 33 m.(110 ft.) from a wall and clap so that the echo coincides with successive handclaps (experience shows this can be done with surprising accuracy - one can easily tell if the clap is a little early or late). The second member of the group then times the claps with a seconds watch. If we find 100 claps (about 20 seconds) takes T seconds, the velocity of sound is 2 x (distance to the wall)/0.01T. This should be repeated ten times, and the average and standard deviation found.

Experiment 7.10 - A paper wave to explain the Doppler Shift

Students with no physics background often have great difficulty understanding the Doppler Shift. It seems incomprehensible to many physics teachers that there is a severe conceptual problem involved here, but discussion with the students shows it is very real.

A simple practical model can be of considerable value. Take a long sheet of paper, and pleat it as shown in figure 1. A simple way to do this for a small class is to fold a 36 cm (14 inch) sheet of lined notepaper alternating up and down at every fourth line (3.5 cm or $1\frac{3}{8}$ inches). This gives about $4\frac{1}{2}$ pleats. Now cut the sheet lengthwise into three equal strips, join the strips together end to end, and you have a transverse paper wave with about twelve oscillations. A larger sheet is necessary for a big class.

The concertina-folded strip is laid on a flat piece of paper whose length represents the distance sound travels in one second. Again, a 22 x 36 cm ($8\frac{1}{2}$ x 14 inch) sheet may be used. For students with little mathematical background, it is convenient to provide two explanations for sound waves, one with a moving source which gives the wavelength shift, the other which gives the frequency shift for a moving observer.

It is a good idea to consider a fixed time such as one second, so to start we take a stationary train emitting a toot one second long. The train may be drawn on a sheet of folded paper. The number of oscillations in one second, f Hertz, (thirteen for the pleated sheet we are using) is contained within the length traveled by sound in one second (V). To demonstrate this, pull the paper wave out from under the paper train, as shown in figure 1. Using the model, it is easy to show $V=f\lambda$.

The second stage in the demonstration is to move the train forward as the wave is slid from beneath it. The train will move forward the distance

it travels in one second (v). In our model, we move the train one inch per second, which is marked on the sheet of paper, whose length we have taken to be the velocity of our sound. The waves now occupy a distance equal to V-v, and the wavelength λ' is now (V - v)/f, where before λ was V/f. In our model, we moved 14 inches in one second, with 13 oscillations, so λ=14/13 inches. If the train moved one inch in the second, λ' = (14-1)/13 = 1 inch. The frequency was originally 13 Hz, and is now V/λ = 14 Hz. - an 8% increase.

In practice, sound travels at 330 m/sec, so a suitable train speed is 30 m/sec, which is 108 km/hr (67.1 mph). If we take the musical note A for the train whistle, 440 Hz, λ=75 cm, λ'=68 cm and f'=484 Hz, 10% higher, almost two semitones. If the observer moves instead of the source, we treat the situation differently.

I use a big paper ear, as shown in figure 2, to represent the observer, and the waves now always occupy a length V since the source does not move. With the observer at rest, it takes one second for the f waves to enter the ear. However, if we move the observer away from the source, in one second the sound will travel a distance V, but the ear will have moved a distance v in this time - so those oscillations in the distance v will not have entered the ear. Again, the distance v can be marked on our sheet of paper. Since there were f oscillations in a distance V, there will be f(V-v)/V in the shorter distance, and the frequency heard by the observer is f'/f = (V-v)/V=1-v/V.

So, in our model, V = 36 cm (14 inches), v = 2.54 cm (1 inch) f = 13(14-13)/14 = 12.02 Hz, a lower frequency. If we are on a train approaching a railroad crossing at 30 m/s where a 660 Hz whistle is blowing, we get f'=f(v+v)/V = 660 (300)/330 = 480 Hz which is not the same as the previous case when the train approached, at the same speed, showing the Doppler effect differs considerably when the observer rather than the source is moving in the case of sound.

Now, f'= original frequency f plus the difference in frequency df.

So $\frac{f+df}{f} = 1+\frac{v}{V}$

and df/f=v/V It is easy for student to remember that the change in frequency, divided by the frequency is the ratio of the velocity of the observer to the velocity of sound. This equation is accurately true for light, whether we speak of the observer or the source moving, because one tenet of the theory of relativity is that we cannot tell whether the observer or the source is moving at constant velocity. It is approximately true for sound, in the general case for both observer or source moving, if the velocities of the observer or source are small. This pragmatic approach to the Doppler Shift really helps those students whose ability to master abstract concepts is restricted.

We can follow the lead of the Australian aborigines to demonstrate the Doppler shift experimentally. They have only two prehistoric musical instruments. The bullroarer, and the didgery doo. The didgery doo is a hollow log about eight feet long or more, which, when blown produces a deep and somewhat monotrous moan. The bullroarer is a flat piece of wood on the end of a long string. The one I use is a piece of 1/8 inch plywood, 3 by 10 cm with a hole drilled at one end to attach a 1 m piece of string. A piece of thick cardboard about the same size also works well. The dimensions are not critical. This makes a strong buzzing sound when whirled round the lead, and a higher pitch as the bullroarer approaches the observer, and lower as it moves away. Unfortunately, the person doing the whirling, being at the center, doesn't hear any change.

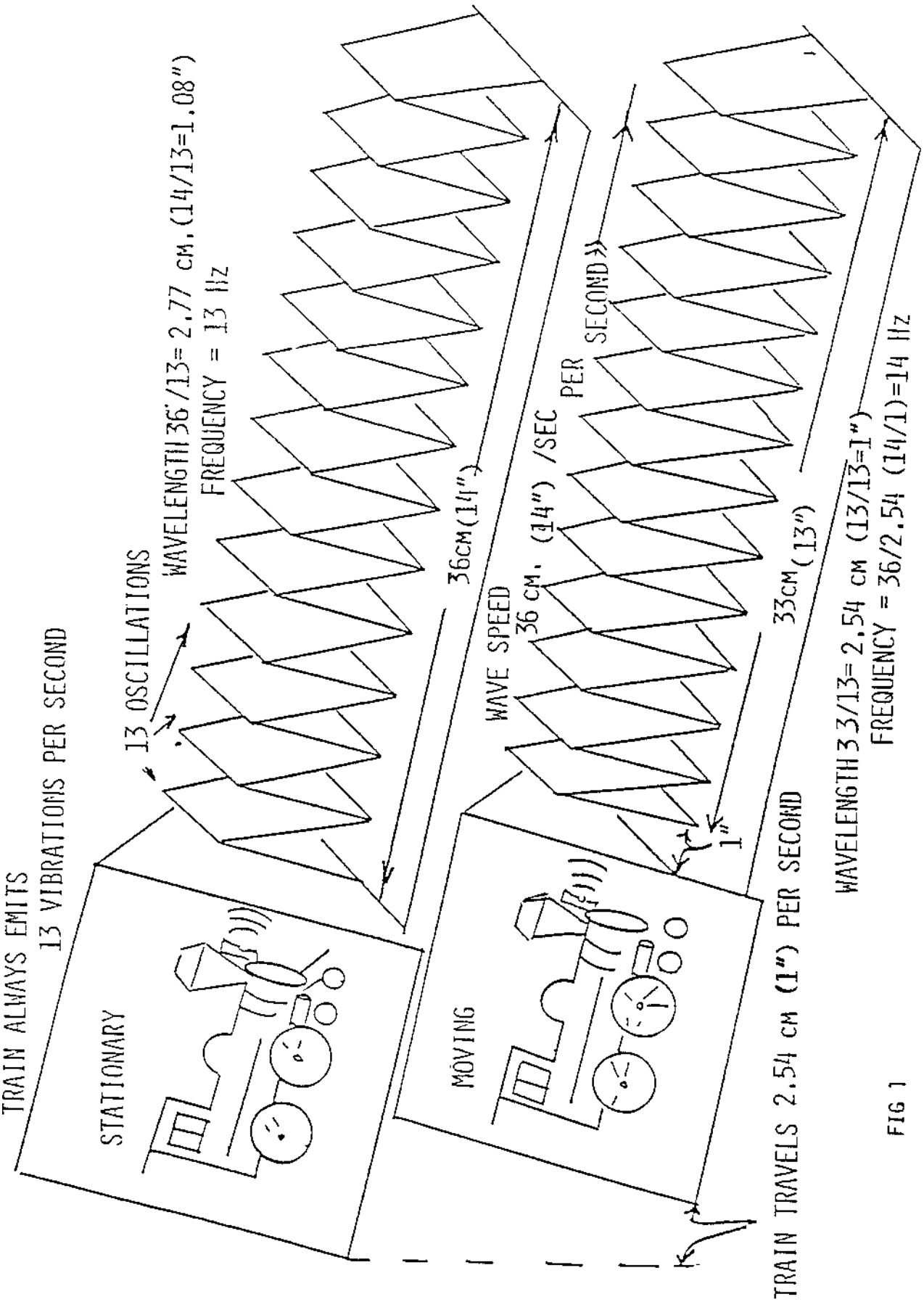

TRAIN ALWAYS EMITS
13 VIBRATIONS PER SECOND
STATIONARY
13 OSCILLATIONS
WAVELENGTH 36"/13= 2,77 cm, (14/13=1,08")
FREQUENCY = 13 Hz
36cm(14")
WAVE SPEED
36 cm. (14") /SEC
PER SECOND
MOVING
1"
33cm(13")
TRAIN TRAVELS 2,54 cm (1") PER SECOND
WAVELENGTH 33/13= 2,54 cm (13/13=1")
FREQUENCY = 36/2,54 (14/1)=14 Hz

FIG 1

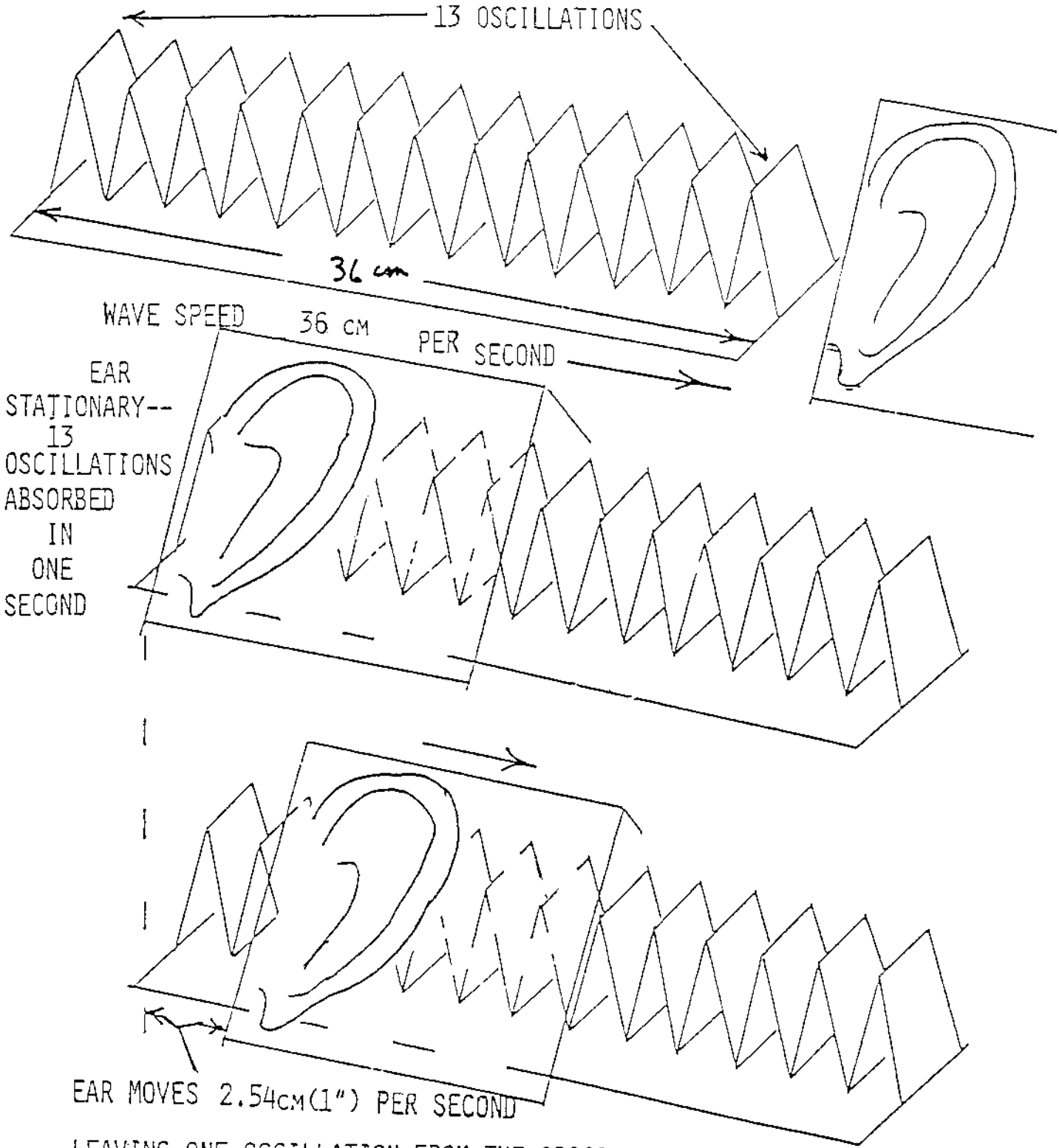

13 OSCILLATIONS
36 cm
WAVE SPEED 36 cm PER SECOND
EAR STATIONARY-- 13 OSCILLATIONS ABSORBED IN ONE SECOND
EAR MOVES 2.54cm(1") PER SECOND
LEAVING ONE OSCILLATION FROM THE ORIGINAL THIRTEEN OUTSIDE

FIG 2

Experiment 8.01 Molecular size

Equipment: Soap, chalk dust, wash bowl.

Procedure: Take the smallest portion of soap you can remove, with a finger nail, or one drop if it is a liquid, and dissolve it in a cup of water--about 500 cc. The soap will be approximately 1/10 gm. Now run a bowlful of tap water, let it settle until it is quite still, then sprinkle chalk dust on the surface. Take one drop of soap solution, and place it on the surface in the center of the bowl. What happens? The soap molecules reduce the surface tension, and the water surface, stretched like a rubber sheet with a hole suddenly punctured in it, pulls the chalk apart where the hole is. The limits of the hole are set by the soap molecules which form a layer one molecule thick. If you measure the diameter of the hole, the area which the soap molecules cover is given by $1/4\ \pi d^2$.

Qualitative: Why do you think the area covered by soap could not spread out forever?

Quantitative: Let the original mass of soap be .1 gm. Its volume will be about .1cc, diluted by 500 cc, of which we take one drop, about 1/2 cc. So we have $\frac{1/2}{500}$ x .1cc soap. The area it spreads is $\frac{\pi d^2}{4}$, so the thickness of the film is

$$\frac{\text{Volume}}{\text{area}} = \frac{\frac{1/2 \times .1}{500}}{\frac{\pi d^2}{4}} = \frac{4}{10{,}000\pi d^2} \text{ cm}$$

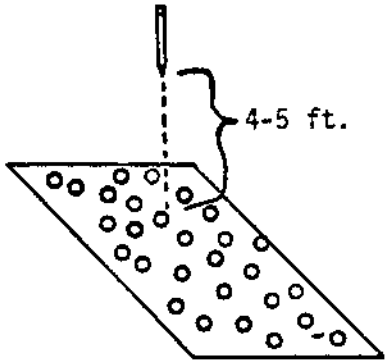
approximately $\frac{1}{10{,}000d^2}$ cm

The maximum size of the film area is provided by its minimum thickness. This occurs when the film is one molecule thick. In fact, soap molecules are long and thin, and like to have one end attached to the water surface, so they are all parallel to one another, with one end in the water. For example, if the molecule were 100 $\mathring{A} = 10^{-6}$cm, d=10 cm. If the open patch covers the whole wash bowl, it shows the molecular size is less than about 10^{-7} cm.

EXPERIMENT 8.02 Nuclear Cross-Section and the size of a Penny

Apparatus: Sheet of paper, pennies, pencil.

Procedure: The object of this experiment is to measure the size of pennies,(or marbles) without actually using a ruler, or any similar measuring device, other than statistics. Take as many pennies as are available (about 40) and lay them out at random, but more or less uniformly (i.e. not all in one corner) on a sheet of writing paper. Now, drop a pencil, point first, from a height of, say, four or five feet, onto the sheet of paper. Neglect all shots that miss the paper, and count separately those shots that hit pennies. (A blunt pencil works best!) Thirty or forty times are necessary.



From this you can find the area of a penny.

Quantitative:

A sheet of writing paper is 8½ x 11 inches, an area of 603.22 square cm (93.5 sq. inches).

The pencil was dropped in a random fashion, and not aimed specifically to hit the pennies. Hence, the chance, or probability it hits a penny is proportional to the ratio of the area of the pennies to the paper. Let the area of penny be A. If there are m pennies, their area is mA. Let the total number of shots be N, and the number hitting pennies be n. Then

$$\frac{n}{N} = \frac{mA}{603.22}$$

and the area of one penny is

$$A = \frac{603.22n}{m\ N} \text{ square cm.}$$

The area of a penny is 2.835 cm^2 (.44 square inches).

How accurate is your answer?

The importance of this experiment is in explaining how the size of the nucleus is measured when it is inaccessible to a ruler. We fire nuclear particles at a target, in the same way we dropped the pencil on the paper, and see how many times they hit a nucleus, and how many times they miss. Knowing the number of nuclei per square centimeter of the target, we can find the area of the nucleus, or its cross section, in exactly the same way we found the area of the penny.

Experiment 8.03 Radioactive Decay--An Analogy

This simple experiment is an effective way to introduce students to the abstract concept of radioactive decay. It was suggested by Shirley Stekel of the Physics Department, University of Wisconsin-Whitewater. It requires beans or marbles of two different colors, although even pieces of paper of the same size but two different colors could be used.

Count exactly 100 red beans and place them in a paper cup or other small container. Have a handful of white beans available in another container. Each red bean will represent a radioactive atom and each white bean a stable daughter atom. The start of the decay process is simulated by taking ten red beans from the cup and replacing them by ten white beans to represent the decay of ten radioactive atoms to their stable products. Then, in a series of trials the contents of the cup is stirred each time and a randomly selected sample of ten beans removed. Each red bean removed is replaced by a white bean and the white beans that have been selected are returned to the cup so that there are 100 beans in the cup before each sample is taken. The number of red beans removed each time is recorded, and the number of red beans remaining in the cup is then calculated. Continue the sampling procedure until only about 20 red beans remain in the cup. Now draw a graph of the number of red beans remaining in the cup versus the sample number. A "half-life" can be determined if it is assumed that the samples were drawn at equal time intervals.

The theoretical curve for this process is an ordinary decay curve and the students' results are usually quite close to the theoretical values at first but tend to deviate as the number of red beans in the cup decreases. The half-life of the beans depend on the ratio of the sample size, S, to the original number of red beans in the cup, n_0.

The sampling process may be simply explained on the basis that 10% of the red beans decay,i.e.are removed from the cup and replaced by white beans, each time. In the case of radioactive atoms, we would say that 10% of the radioactive atoms (red beans) decay to stable atoms (white beans) in the time taken for each sampling. Thus, 10 red beans are removed the first time, leaving 90 red beans, and 10 white beans. From now on, we cannot predict the exact number of red or white beans we shall pick - we could pick 10 red or 10 white beans. However, since there is one white bean for every nine red beans in the cup, this is the proportion, and in fact the number most likely to be selected statistically. We will now have 81 red beans, and 19 white beans. The next throw removes 10x(81/100) or 8.1 red beans, leaving 72.9 red beans, so 7.29 will be taken next time, leaving 65.6, and so on.This calculation, and the average of five experiments, is shown in the figure. The increased accuracy of averaging five runs or sampling 50 out of 500 is worth it, if time is available

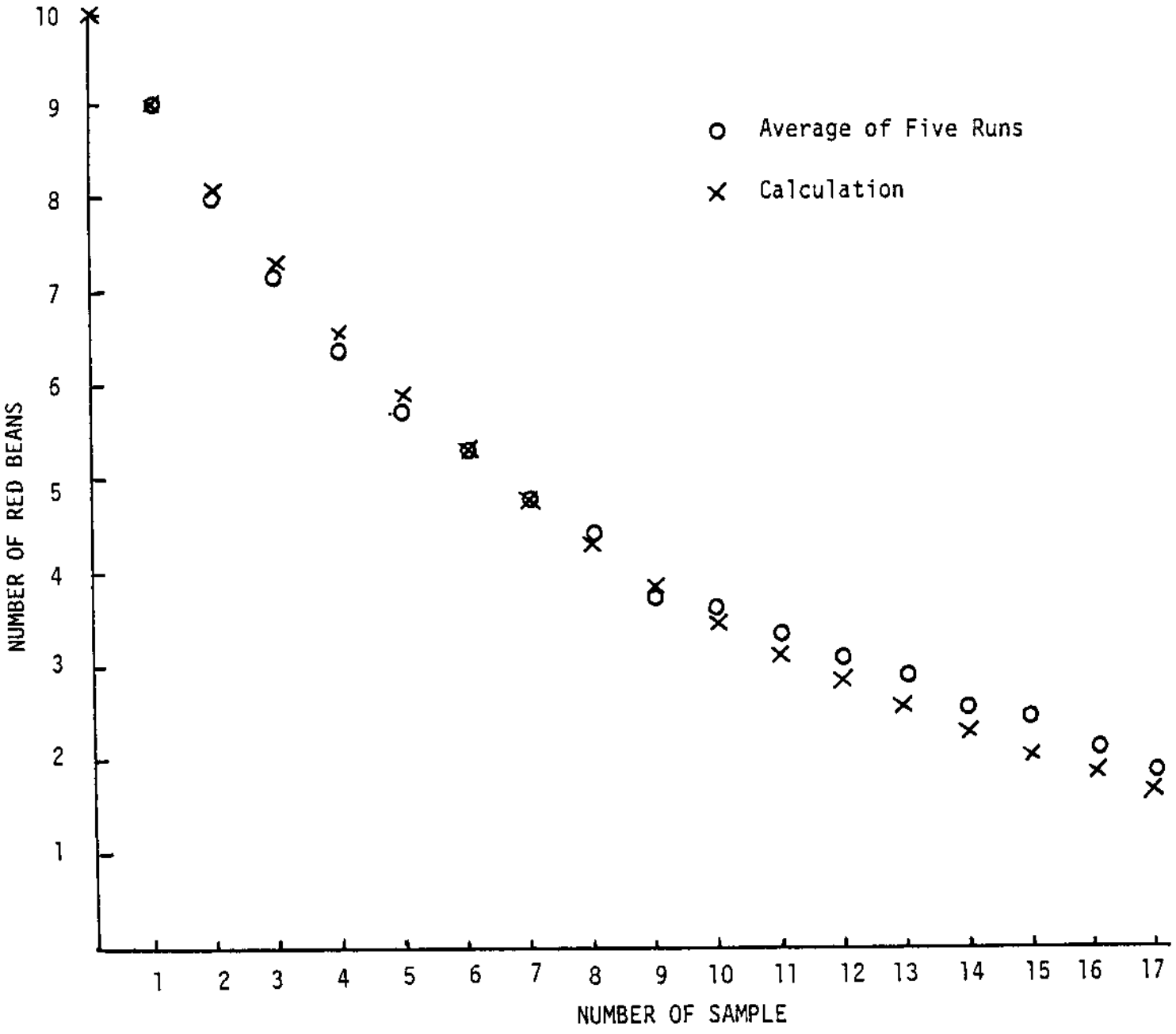
To relate this to the conventional decay formula, the number of red beans drawn in any given sample n is proportional to thenumber left, n.

$$S\ n = n \qquad (1)$$

This leads to the relationship

$$n = n_0 \exp -(t/S)$$

where t is the number of the sample. This assumes the sample n is so small that we can integrate (1) . Since this is not in fact the case, the formula is only approximate. The half life (the time it takes for half the radioactivity to decay, or in our case, half the red beans to be converted to white) should be given by $T_{\frac{1}{2}} = S \ln 2$ which, for 100 beans sampled 10 at a time, would be seven samplings. If we went by time (as we do with radioactivity) and sampled once a minute, it would be seven minutes.


10
9
8
7
6
5
4
3
2
1
NUMBER OF RED BEANS
Average of Five Runs
Calculation
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
NUMBER OF SAMPLE

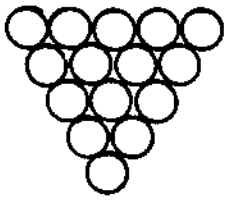
Experiment 9.01 The Packing Together of Atoms in Metals

Materials: marbles, paper, sticky tape

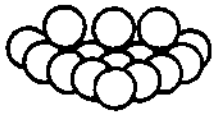
Procedure: Take a piece of tape, and attach five marbles, as shown, as close together as possible.

Attach four more marbles to a second strip, adjacent to the first, as shown

Continue doing this until you have a triangle of marbles similar to that on a pool table, so

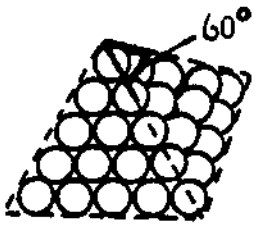


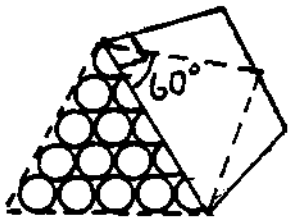
It is clear that this is as close as possible that marbles can be placed on a flat sheet, and this is the way atoms, such as metal atoms pack together when they are attracted to one another. However, a metal does not consist of merely one flat sheet of atoms, but is solid. How does the next layer go down? Put marbles down on top of the layer you made, and you will see they fit into the cracks as shown. So there is



only one way to put two such layers together. However, now try putting on a third layer, and you will find there are two different ways you can do so. In one, each marble of the third layer will be directly above a marble of the bottom layer. Such a structure has sixfold symmetry, and is called hexagonal. In the other, the atoms of the third layer do not lie directly above atoms of either first or second layers. Such a system has cubic symmetry. To examine this, continue piling marbles on until you build a little pyramid as shown.

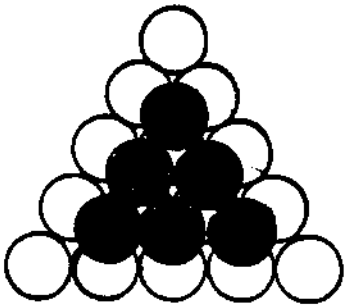
Such a pyramid, which is the way in which cannon balls are piled outside a courthouse, form a regular tetrahedron, the sides of which are all equilateral triangles, the corners all being 60°, two thirds of a right angle, as you can see by holding the corner of a sheet of paper on one side.





Three sides meet at the top, showing threefold symmetry about the corner.

Remove the marbles down to the bottom layer, and put down a second layer, composed of six marbles, as shown.



Then place one marble on top of the pile in the middle. If you measure the angle of the corner with a sheet of paper again, you will find it is 90°, as are the corners of a cube. This shows that, the cubic symmetry we obtain by piling marbles is actually arranged so that one is building the corner of the cube, which has an axis of three fold symmetry passing through it, since again three sides meet at a corner.

Notice, if we label the layers from the top down which we used to build the tetrahedron, 1, 2, 3, 1, 2 where all the 1's and 2's lie vertically above one another, the corner cube would be 1, 3, 2 - both have the three layer scheme, but arranged in a different order.

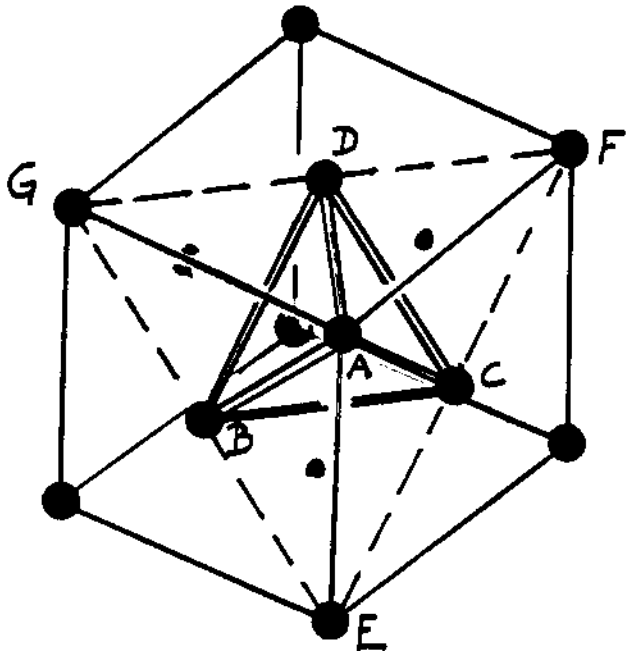
The cubic packing we have examined is called "face centered cubic". We can see why by looking at the diagram below. "A" forms the corner of the cube we have built, and looking at the whole cube we have drawn, we see there are atoms at each corner, and at the center of each face of the cube. ABCD is the tetrahedral structure we built, and the addition of GFE turns it into the corner cube. See if you can pick out the whole cube from the second structure of cubic symmetry you built.

Qualitative Question: How do you think you could tell a cubic metal crystal from a hexagonal crystal? Do you think any other structures are possible besides cubic and hexagonal? Try with the little pile of marbles.

Magnesium, scandium, titanium and cobalt all have hexagonal close packed structures. Aluminum, nickel, copper, silver and gold all form close packed cubic structures.

Quantitative: Do you think the crystal size is the same if the same number of atoms are packed in a hexagonal or cubic array?

You can try this out, experimentally, by measuring the outside dimensions of the pyramid or the equivalent hexagonal structure.



INTRODUCTION TO SECTION 10

Electrostatics

One of the problems in devising experiments employing cheap and easily available materials has been to find equipment for electrical experiments - particularly electrostatic experiments. The most satisfactory solution appears to be the (empty) aluminum soft drink (or beer!) can (12 oz) which can be used for inumerable purposes. Unlike the old steel cans, the aluminum may be cut easily with a pair of scissors, and without ruining the scissors. The edges of the cut metal are not as sharp as the steel cans, and the sheet can easily be bent with the fingers - yet it is robust enough, unlike aluminum foil, to retain the shape which it is given, even under stress. This item of garbage must definitely be added to our list of resource materials.

10.01 THE ELECTROSCOPE

To make an electroscope from an aluminum can, first, cut off the top and bottom, and slit the side, so that it can be opened out flat to give a sheet approximately eight inches by four inches (10 x 20 cm).

The electroscope is a device which measures the charge on itself, (and hence the voltage of whatever supplied that charge). The type described employs the mutual repulsion of a vane and its support, having charges of like sign.

Digression

At this point let us digress to examine one of the interesting features of the can itself. Aluminum drink cans, in general, are deep drawn - that is to say, the metal is squeezed in forming the can so that it runs from the bottom producing the sides of the can. X ray diffraction shows that aluminum crystallites align in a direction along the length of the can, rather than perpendicular to it. This affects the physical properties of the metal. To see this, cut two identical strips of aluminum from your sheet, say ¼ inch by 4 inches, with one cut along the "grain" (i.e. the length of the can) and the other perpendicular. Flatten the two strips carefully, then hang a quarter using sticky tape, from the end of each, and let them hang the same distance over the the table, as shown in figure 1. You will find the strip cut along the length deflects much less than that cut perpendicular to the axis of the can. This shows the coefficient of elasticity, (stress/strain), is larger for the strip cut along the length, in much the same way that wood has a higher coefficient of elasticity (Young's modulus) along than across the grain.

Returning from our digression, cut the shapes shown in figure 2 from your aluminum sheet. Now, bend the larger piece as shown in Fig. 3, and place the smaller piece, the vane, to balance on the pivot region A. The vane should be top heavy at first, and overbalance. Cut small pieces from the top of it until it just does not overbalance.

The electroscope must be insulated, so tape it to the bottom of an upturned styrofoam cup as shown. Humidity is the greatest enemy of electrostatic experiments. If your experiments do not work, it is quite likely because humidity has condensed on the insulators, allowing the charge to leak away. Hence, make sure the air is dry - in summer air conditioning will help, and in winter a hot dry room is best. Do not bring cold insulators into a warm room - moisture will inevitably condense on them to produce a conducting layer.

Since the sensitivity of the instrument depends on the position of the center of mass of the vane, each electrometer is different and requires a special calibration. However, the foil in which chewing gum comes wrapped also makes a suitable vane and it is very light, and of uniform thickness. Cut a piece of the wrapper, as shown in figure 4, making it as flat as possible, then fold over the top, and hang it (metal side inward) as shown on a support cut from the aluminum sheet with the dimensions given. We used the foil from Wrigley's double mint gum. The diagram shows the angle at which the foil will sit as a function of the voltage applied to the electrometer. It is not a linear scale, because the torque depends on the square of the charge in addition to its distribution as a function of the angle.

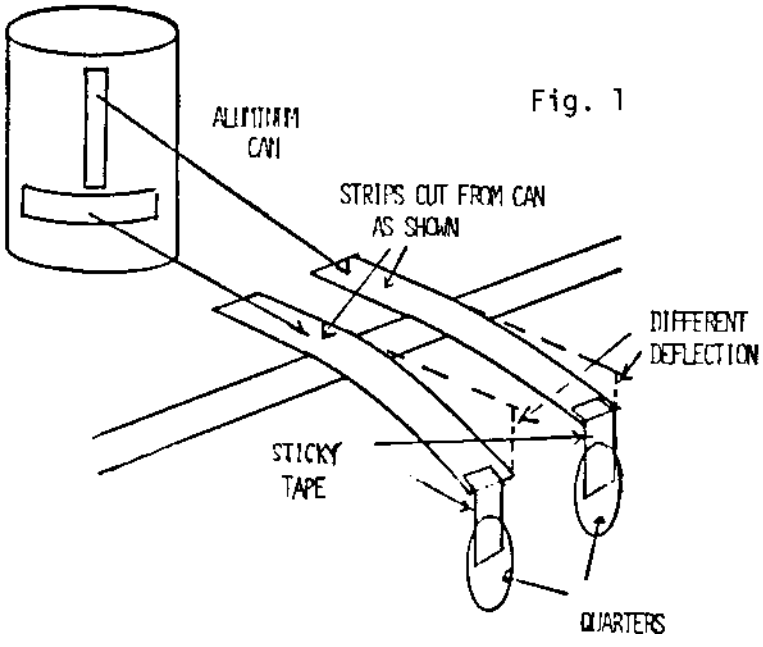


Fig. 1

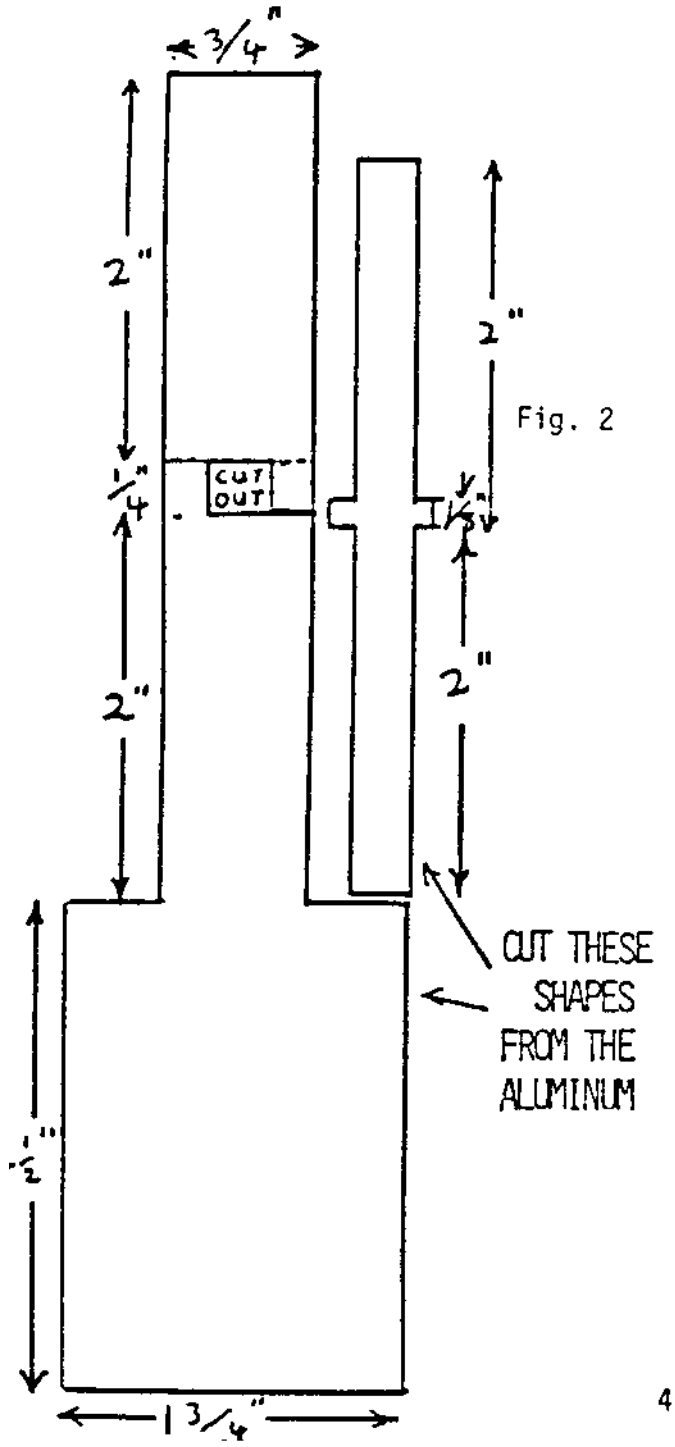


Fig. 2

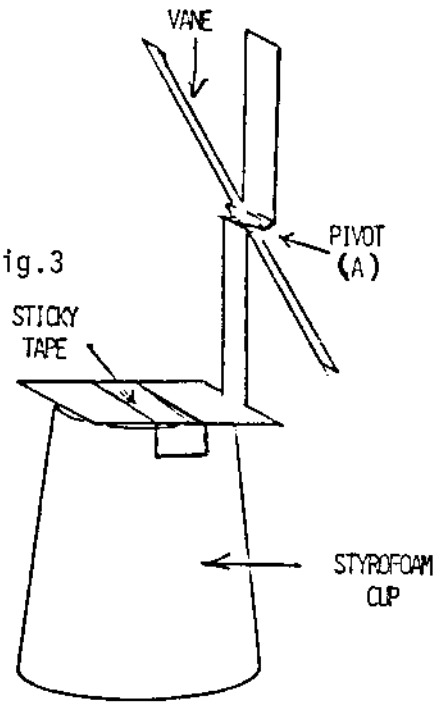
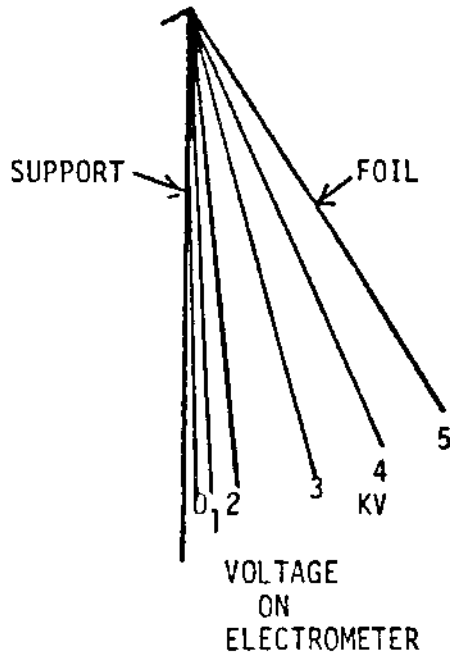


Fig.3



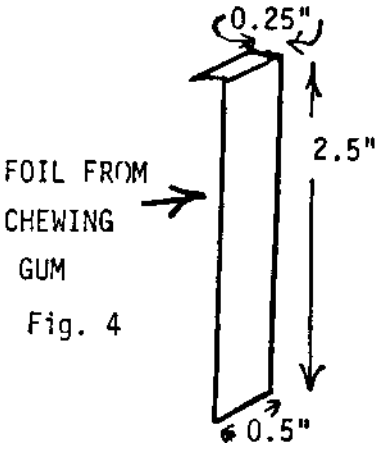
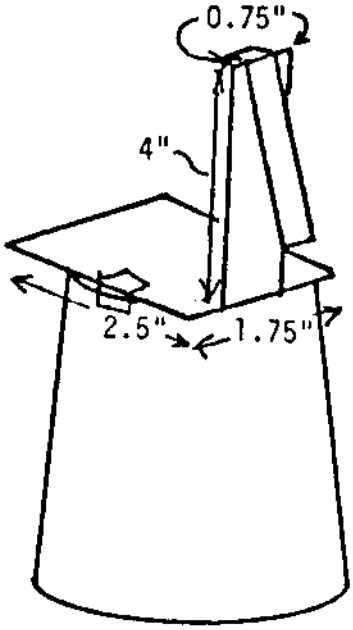


Fig. 4



10.02 The "Versorium" - a simple charge detector

It has been known since the time of the Greeks, that when amber, a natural yellowish fossil resin coming from trees, is rubbed, it will attract small bits of matter. From the Greek name for amber comes our work electricity, and the frictional process by which it is electrified is known as triboelectrification.

William Gilbert, a sixteenth century English scientist (and incidentaly Queen Elizabeth's physician) divided materials into "electrics," which he could electrify, and "non electrics" which he was unable to electrify, and which today we call insulators and conductors. It was left to Benjamin Franklin to suggest that there is really only one type of electricity, present to differing degrees in uncharged or neutral bodies. An excess of this in a body he called positive, and a lack of it negative.

Hang a drinking straw by a fine thread, or support it on a pin. Charge another straw by rubbing with a cloth, and bring it near the first. It will move. Such a device was invented by Gilbert who called it a "Versorium." Now make sure the first straw is charged with the same sign electricity as the second by rubbing with the same material. You will find the two repel one another, a simple way of demonstrating like charges repel. The versorium will tend to stick to the cloth used to rub it, showing unlike charges attract. (Since the charge on the straw is rubbed off the cloth, they must be charged of opposite sign.) If rubbing together A and B makes A+ and B-, and rubbing materials B anc C makes B+ and C-, then if materials A and C are rubbed together, A will become + and C - . Hence substances can be organised in a sequence called a triboelectric series, where a substance will be given a positive charge if rubbed by a second substance below it in the series, and correspondingly a negative

charge if above it. The series (Table 1) drawn from the Smithsonian tables, is at best approximate - glass rubbed by rabbits' fur may not always be negative - it depends very much on the rabbit.

The electroscope you have built can be used to check this series, but to do so, and also for many other experiments, it is useful to have an "electrophorus," a device for putting a fixed charge on the electroscope, or other conductors.

Table 1

asbestos

fur (rabbit)

glass

mica

wool

quartz

cat's fur

lead

silk

human skin, aluminum

cotton

wood

amber

resins

Brass, Cu, Ni, Co, Ag etc.

rubber

sulphur

metals (Pt Au)

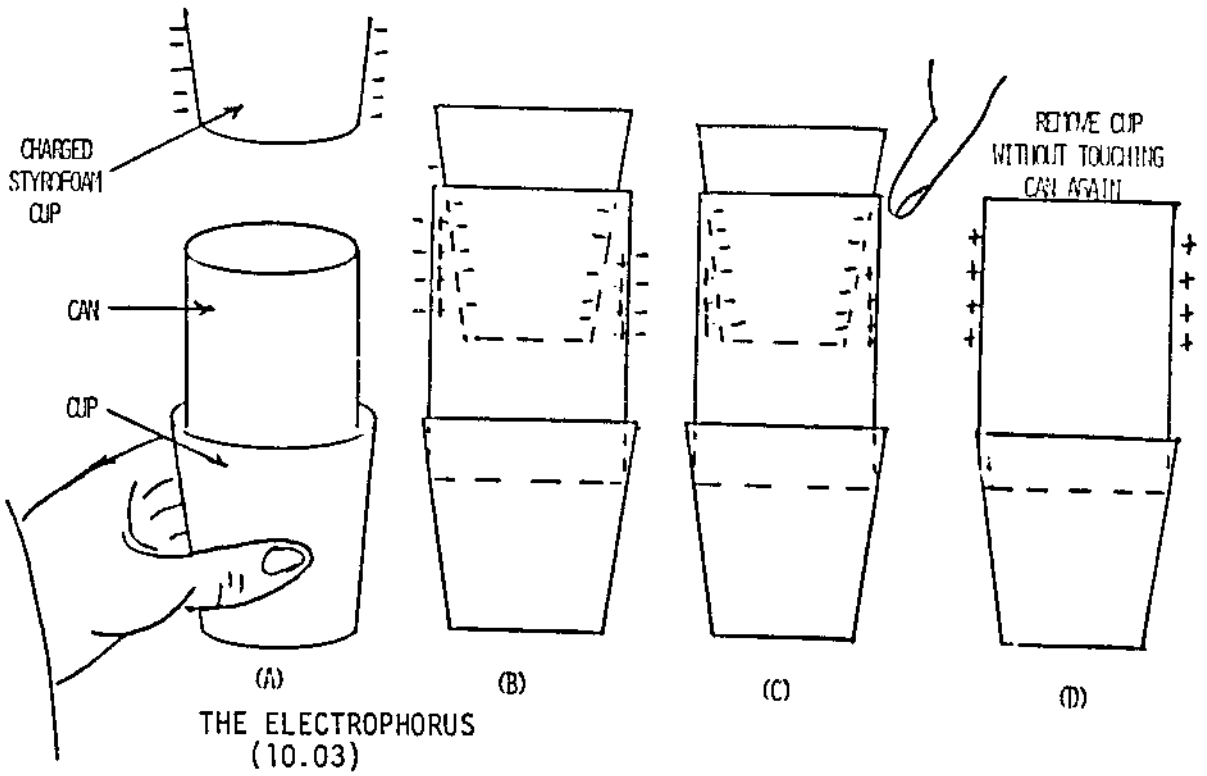
celluloid

India rubber

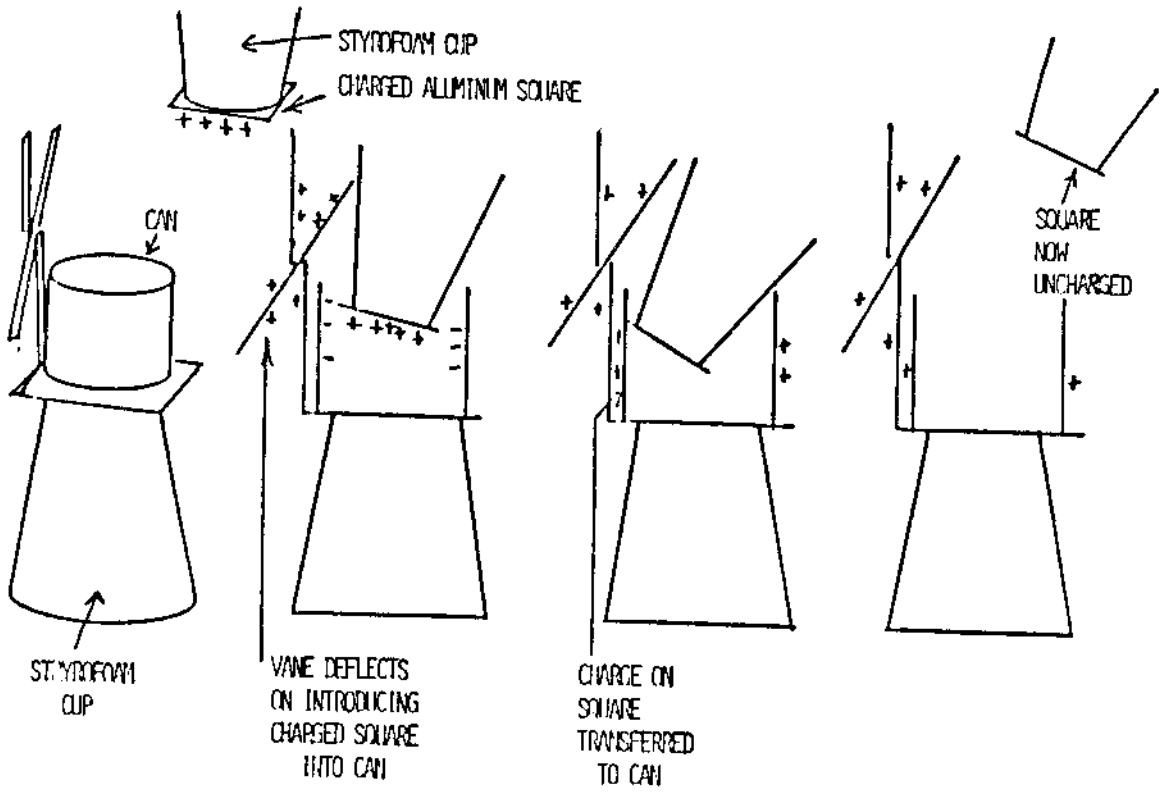
10.03 The electrophorus

The electrophorus demonstrates charging by induction, and the principle of electrostatic machines, such as the Wimshurst machine.

Cut the top off an aluminum can, and stick the botton end of it in a styrofoam cup, to act as an insulating support, as shown in figure (a). Now, charge a second cup by rubbing it on your jacket, your hair, or some suitable fabric. The cup will likely have a negative charge. Place the bottom end of the charged cup in the can, as shown in figure (b). The negative charge on the cup induces a positive charge on the inside of the can. Holding the can in one hand by the styrofoam cup in which it sits, touch the outside of the can to draw off the negative charge present there through your finger (Fig. (c)). Lastly, remove the charged cup. (Fig. (d)) The can will now be positively charged, and on touching the electroscope, charge will be transferred, causing the vane to rotate away from the support, because of the repulsion of like charges. Note, no charge was removed from the styrofoam cup - hence after discharging the can we can repeat the whole process, and transfer as much charge as we want to another conductor via the can, until the conductor is at the same potential as the charged can. This is the principle of electrostatic machines - only, instead of transferring the charge manually, it is done mechanically by the machine.



THE ELECTROPHORUS
(10.03)



FARADAY ICE PAIL EXPERIMENT
(10.04)

10.04 The Faraday Ice Pail Experiment

In 1843 Michael Faraday used an ordinary pewter ice pail for a number of electrostatic experiments, some of which showed there was no electrostatic field inside the pail, and therefore all the charge resided on the outside. We can repeat this experiment by using an aluminum can with the top cut off in place of the pail. Put this on the plate of the electroscope. Cut a piece of aluminum about two inches square, and stick on to the bottom of a styrofoam cup as shown in figure 6. Charge up a styrofoam cup, place the metal square on it and ground it, as you did before, with the electrophorus. The charge on the plate will be less than that on the can used previously because of its size. Now place the square inside the can on the electroscope, and touch the inside of the can with the metal square. If all the charge resides on the outside of a conductor, the square will be discharged and the charge run to the outside of the can. Remove the can from the electroscope and discharge it. You can now check that there is no charge on the square. We can now recharge the square as before, and repeat the process of transferring charge to the can on the electroscope as often as we want, raising the potential of the can much higher than that of the square before it is inserted in the can, until ultimately the can will spark over to ground, if the insulators are sufficiently dry. This is the principle of the Van de Graaf machine, but in this machine the charge is carried to the inside of the conductor via a belt.

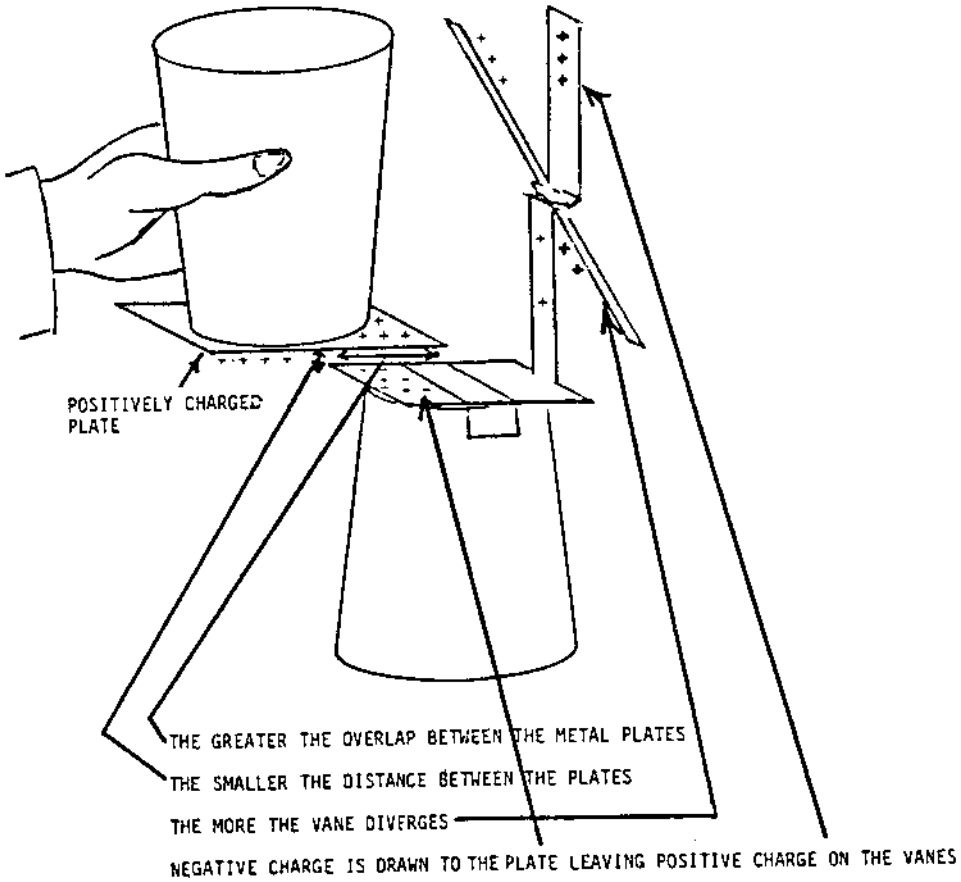
10.05 Capacitance

Electrostatic charge is stored in a capacitor or condenser. The earliest form of this was the Leyden jar, a glass vessel with a metallic coating on the inside, and a second insulated from the first on the outside. What conditions are required to store the most charge?

To see this, take the charged metal square you have, and gradually bring it close to the plate of the discharged electroscope. Note that the vane diverges more and more the closer the charged square is to the plate of the electroscope - that is because the negative induced charge is drawn to the plate, leaving the vane and its support positive. Hence, to store charge the plates of the storage vessel should be as close together as possible. Now, overlap the charged square with the plate of the electroscope, keeping them the same distance apart. Again, when the overlap is small, the vane moves little, but with a large overlap it moves much, showing much charge has been drawn to the plate. So, the best capacitors have a large area, and a small separation between the plates.

Charge the electroscope with the charged plate until the vane is at about 45°. Now, try bringing up various objects which have been rubbed by other materials, and check out the triboelectric series. Put a can on the plate of the electroscope and discharge it. Rub a small straw with a small piece of paper or cloth (a sheet of toilet paper works well.) Put the paper in the cup - the vane moves out. Add the straw, and it moves back, showing the gain in charge by the paper was equal to that lost by the straw - but - make sure both are discharged to start with. Straws charge very easily.

10.05


POSITIVELY CHARGED PLATE
THE GREATER THE OVERLAP BETWEEN THE METAL PLATES
THE SMALLER THE DISTANCE BETWEEN THE PLATES
THE MORE THE VANE DIVERGES
NEGATIVE CHARGE IS DRAWN TO THE PLATE LEAVING POSITIVE CHARGE ON THE VANES

INTRODUCTION TO SECTION 11

EXPERIMENTS IN MAGNETISM

Additional equipment is needed to perform experiments in magnetism, specifically a magnet! Cheap magnets can be obtained at any dime store, and such magnets can be used for the experiments below. The most suitable magnet, however, is one of the chubby alnico type, and a small bar magnet is probably best. For a class, the small cylinder magnets (2/3" diameter), or even the break-off magnets sold by the Edmund Co. of Barrington, N. J. 08007, are quite suitable. The cylinder magnets cost about 8 for $2.50.

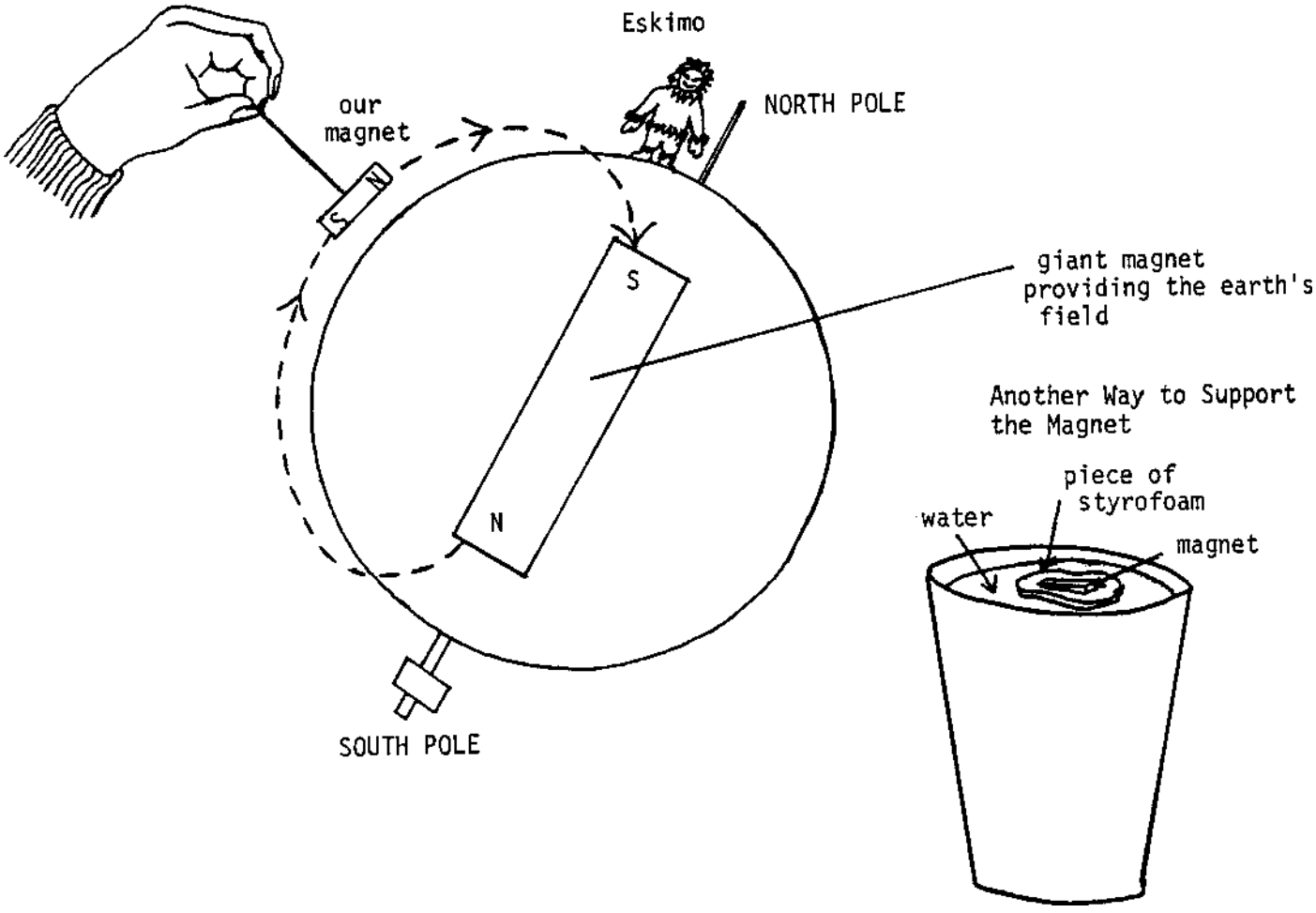
Experiment 11.1 - Why is the North Pole South?

Equipment: Magnet, cotton

Procedure: Take about three feet of cotton, or unwind a thread from a piece of string the same length. Attach it to the center of the magnet. Hold the thread at the top end, and notice the magnet always points in the same direction. That end of the magnet pointing north is called the north-seeking pole, or more often, the north pole. However, as we shall see from experiment 11.3, the north pole of one magnet is attracted to the south pole of another. So, if we regard the earth as a big magnet, its south magnetic pole must be in the north, as shown. In fact, it is thought that the earth's field is provided largely by the circulation of conduction fluids inside the earth. Mark the North pole of the magnet in pencil with an N.

The way in which the force provided by a magnet can act through space mystified past scientists when there is obviously nothing joining the magnet and the object it attracts. They were looking for something like a connecting piece of string, or a spring. Our present day knowledge of atoms and electrostatic fields now makes us realize that even a piece of string is held together by electrostatic forces - concentrating our problem to what is such a field? Today, though we know much more about fields of force, the basic problem is still unsolved.

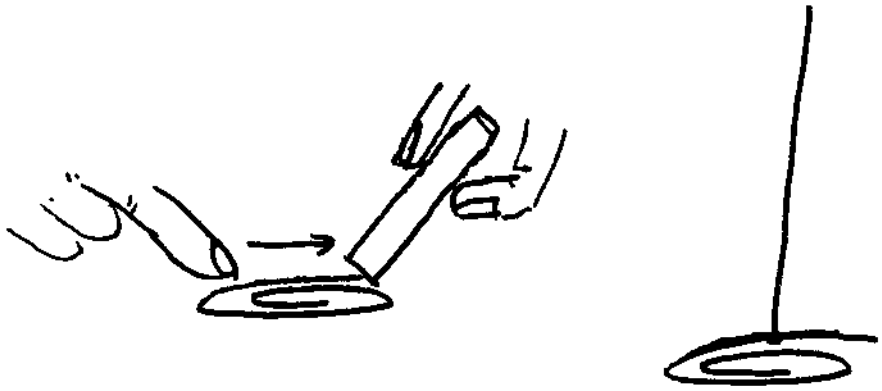
It used to be thought that a magnet breathed on by someone who had eaten garlic would remove its virtue. Luckily, this has proved untrue.



Experiment 11.2 Making a magnet, and using it as a compass.

Materials: cotton thread, or a fine thread untwined from the string, paper clips, magnet.

Procedure: Hold the paper clip on the table top, and stroke it from end to end, with one pole of the magnet, a large number of times, always in the same direction. Hang the clip from a thread, as shown, so that it balances



horizontally and see in which direction it points. Which is it?

Note that the end of the clip where the stroke finishes has opposite polarity to the pole doing the stroking, as shown. Does the south pole of the magnet attract the north pole or the South pole of the paper clip? Does the south pole of the magnet repel the south or the north pole of the paper clip? Convince yourself that like poles attract, and unlike poles repel.

Experiment 11.3 - Lines of force around a magnet.

Equipment: Magnet, paper clip, cotton thread, pencil.

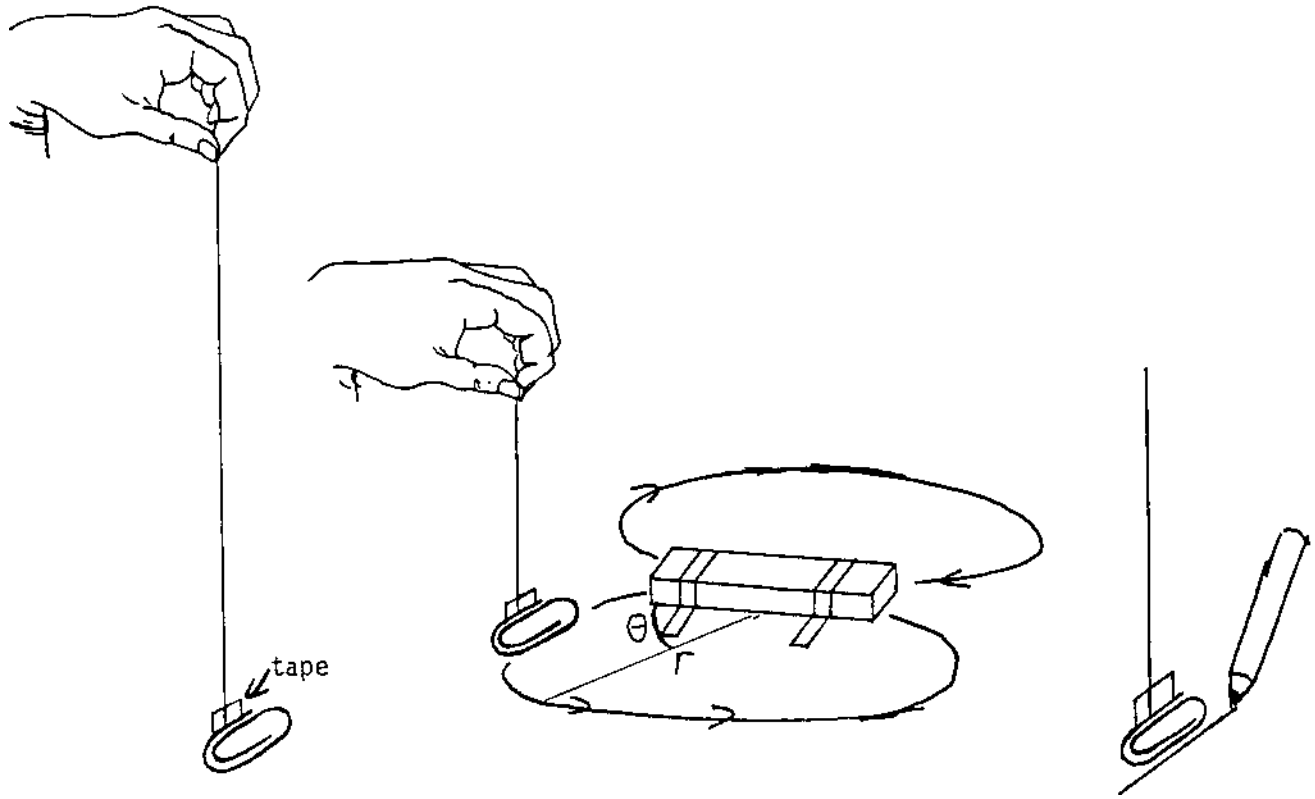
Procedure: The lines of force should follow curves whose formula is $\frac{\sin^2\theta}{r}$ = constant.

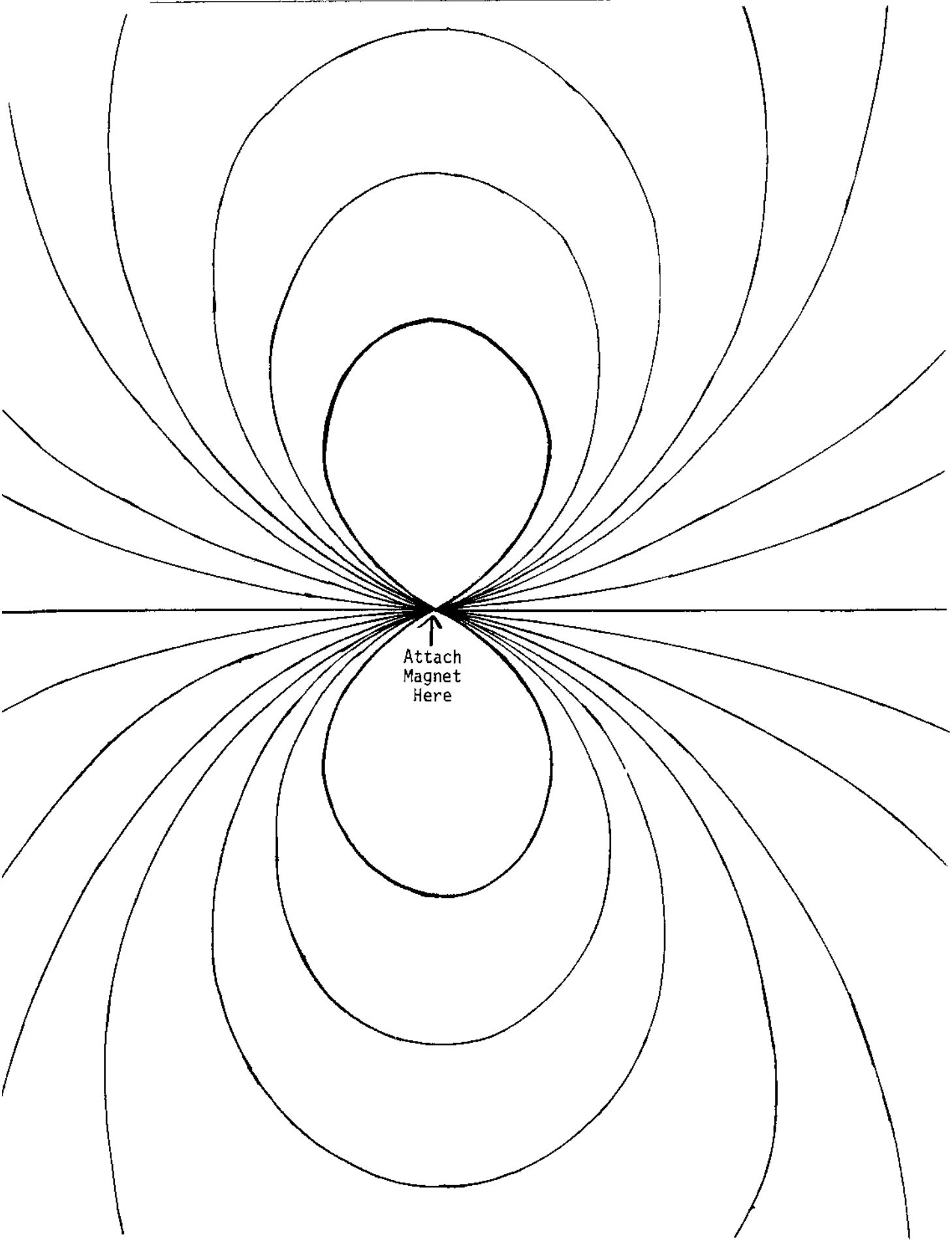
where θ is the angle the radius vector r makes with the axis of the magnet.

This experiment is to test this theory.

The curves are plotted on the next page. Place the magnet so the poles lie symmetrically along the line shown and tape it in place. It is best to orient the magnet North South, so that the earth's field affects the direction of the line of force least.

Support the magnetized paper clip using a piece of cotton thread, and hold it as far along the cotton as possible, as shown. A small piece of tape on the clip air-damps vibrations. Support the clip somewhere adjacent to the magnet, and gently lower it to the paper. Then draw a line along the edge of the clip just touching the paper. This is a field line, and should be parallel to the field loops drawn,as shown. Do this all around the magnet, holding the cotton closer to the clip as you approach the magnet, to prevent it being drawn in.

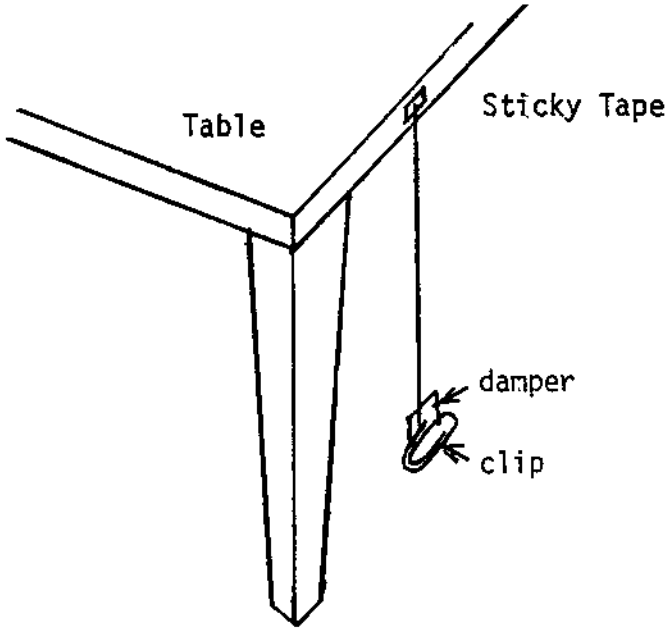



Attach
Magnet
Here

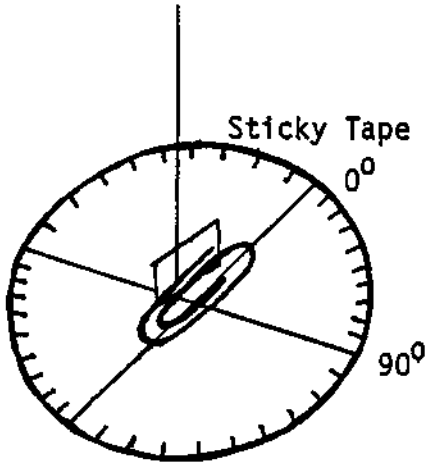
Experiment 11.4. Tangent Magnetometer, and Magnetic Strength of a Bar Magnet.

Materials: magnet, paper clip, cotton thread, paper protractor.

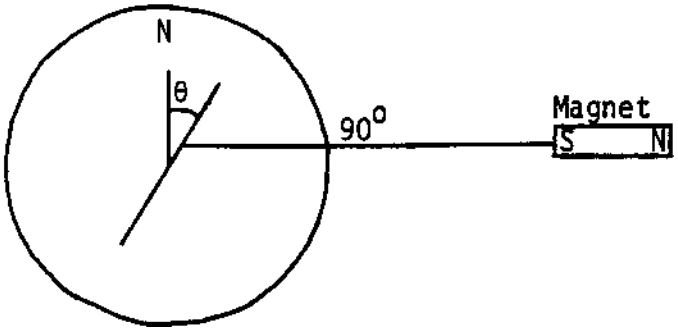
Procedure: Take the magnetized paper clip and hang it by a long thread from a table or chair to sit just above the floor.



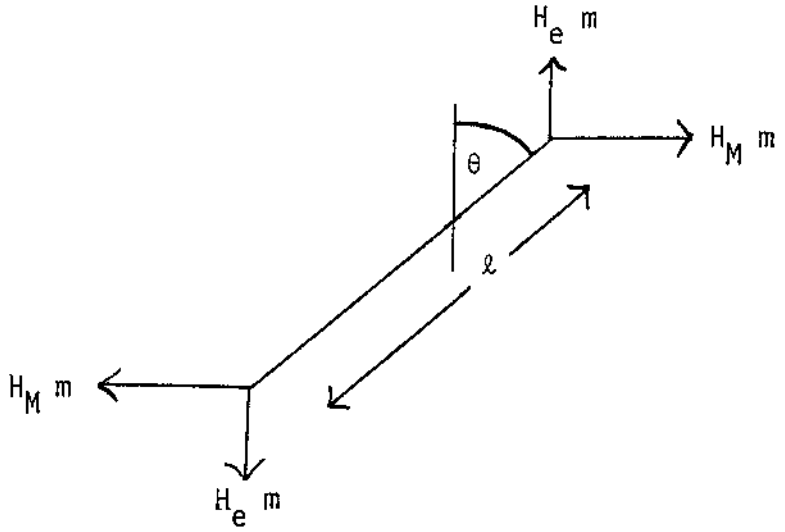
Make sure the thread is unwound. A piece of sticky tape attached to the clip will help damp out oscillations. Place the protractor beneath the clip, so that it is aligned at 0°.



Bring up the magnet along the 90° line.



There are two forces acting on the clip. That produced by the earth's field H_e and the force due to the magnet, H_M. When the paper clip is sitting at an angle θ, as shown, the forces produce two couples, trying to twist the clip in opposite directions.

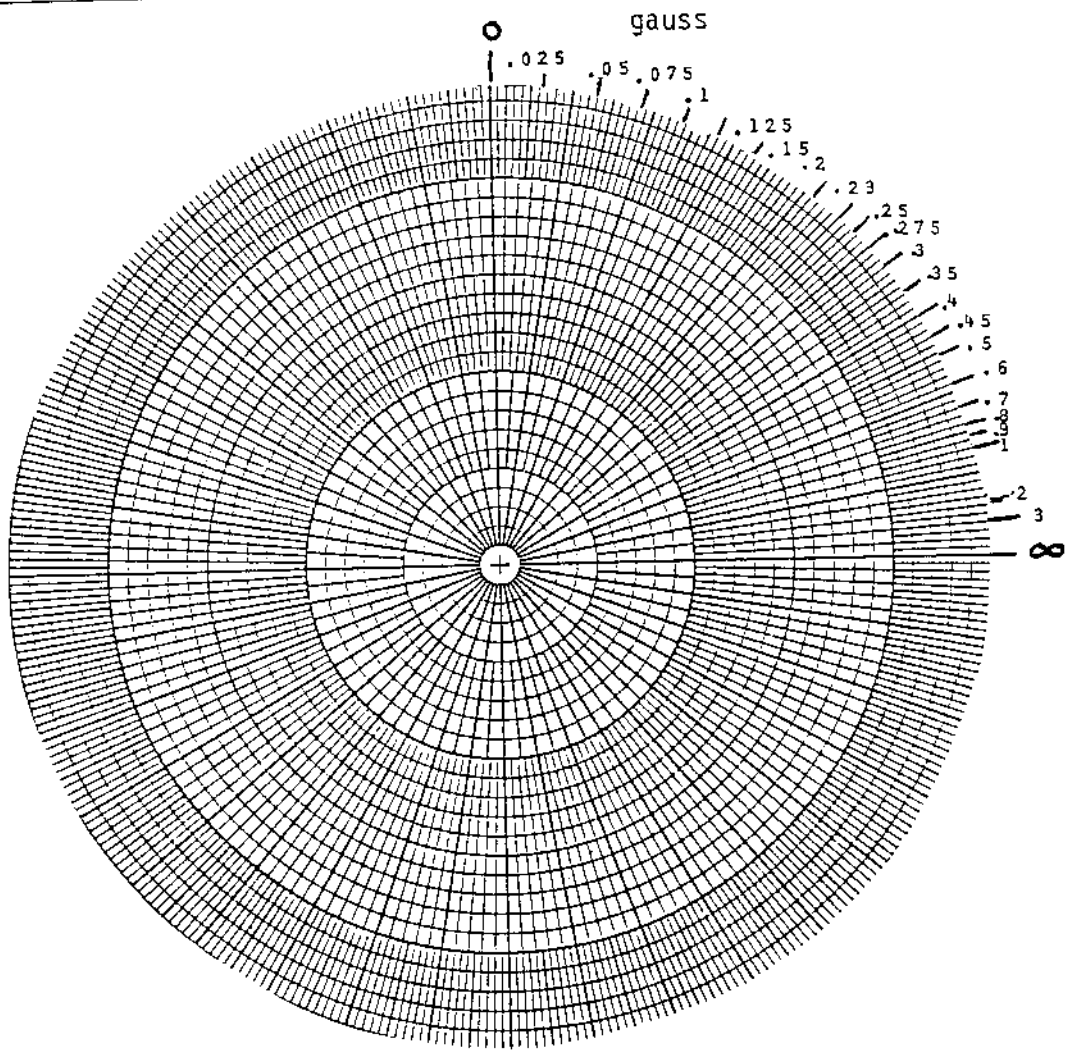


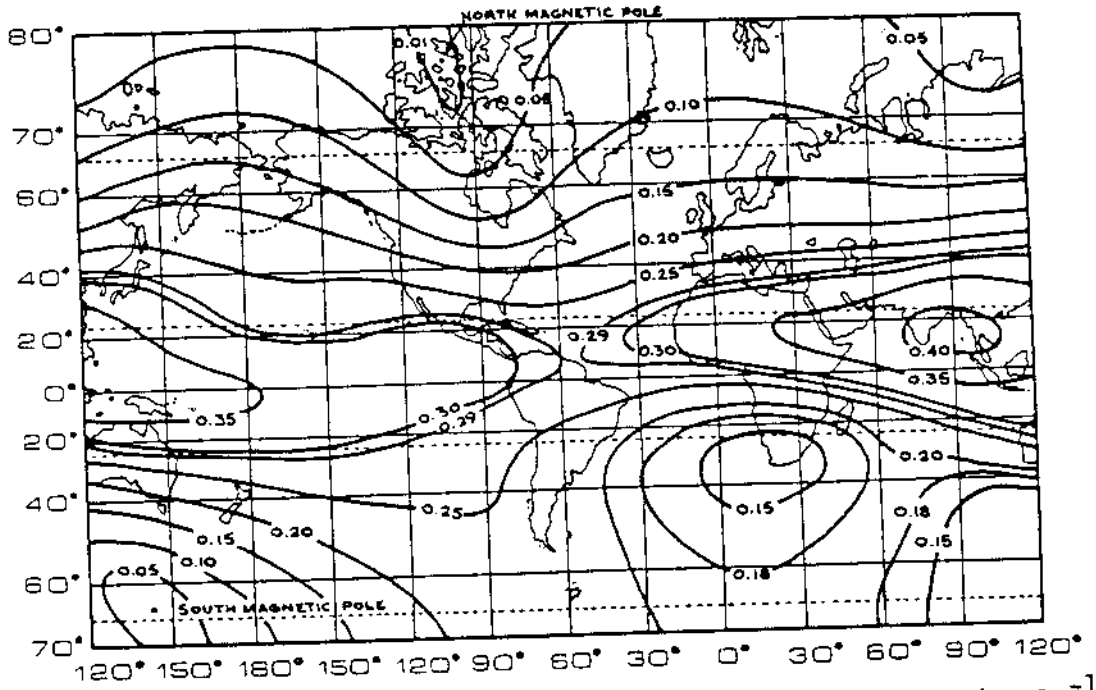
The couple due to the earth is $mH_e\ell \sin\theta$, and due to the magnet $mH_M\ell \cos\theta$.

Then $$m H_e \ell \sin\theta = m H_M \ell \cos\theta$$

and $$\tan\theta = \frac{H_M}{H_e}$$

Now, H_e is .23 gausses in South Carolina, and hence $H_M = .23 \tan\theta$.
The outside of the protractor has been graduated in units of .23 tan θ, so, if we arrange the magnetic field we wish to measure to be perpendicular to the earth's field (as it is with the magnet placed as shown), we can read its value directly off the circle. In Florida, the horizontal component can be up to .29, and in Maine it is .14 to .16 gausses.



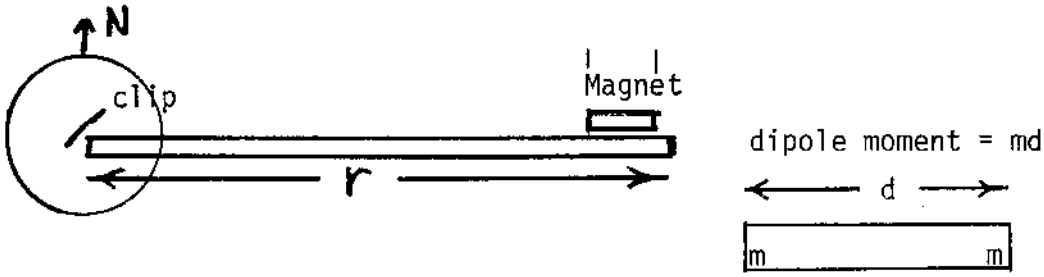


Map showing lines of equal geomagnetic horizontal intensity H (in 10^{-10} tesla or 10^{-6} gauss) for 1975 (U.S. Naval Oceanographic Office)

EXPERIMENT 11.5. The force law near a bar magnet.

Materials: Pencil, Magnet, paper clip and cotton thread.

Procedure: Place a centimeter ruler on the floor starting from the paper.



Now, measure the field strength as a function of distance from the magnet.

Distance from the magnet r(cm)	Field strength (gausses)	r^3	Magnetic dipole moment = Field Strength xr^3 (gauss cm^3)	$\frac{1}{r^3}$
5		125		.008
6		216		.00463
7		343		.0029
8		512		.00195
9		729		.00137
10		1000		.001
15		3375		.00029
20		8000		.000125
25		15625		.000064
30		27000		.0000370

Multiply the field strength by r^3, and record the result. Is it constant? If so, it shows the field strength is inversely proportional to the cube of the distance from the magnet. Alternately, you could plot the field strength against $1/r^3$ which would be a straight line through the origin, if the field strength $\propto 1/r^3$.

The field drops off from a bar magnet more quickly than from a point pole or charge ($1/r^2$).

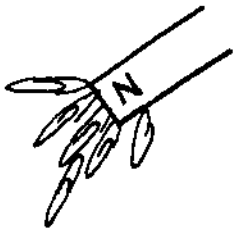
The dipole moment of the magnet is the field strength xr^3 in units of Gauss cm^3.

(1 Weber/m^2 = 10^4 Gauss)

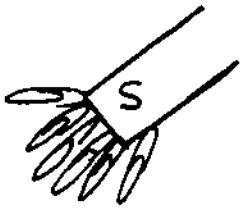
EXPERIMENT 11.6: Strength of bar magnets.

Materials: Magnet, paper clips.

Procedure: The pole tip strength can be estimated by hanging paper clips from the magnet as shown.



Hang the paper clips from the first one, then the opposite pole.



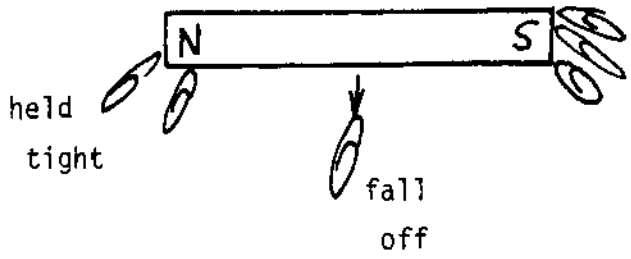
Can you hang the same number of clips from either pole? If so, this shows that the pole tips of a magnet must have equal, but opposite strength.

This is not an accurate experiment, because the paper clips have a certain amount of inherent magnetisation, but it does give a rough answer.

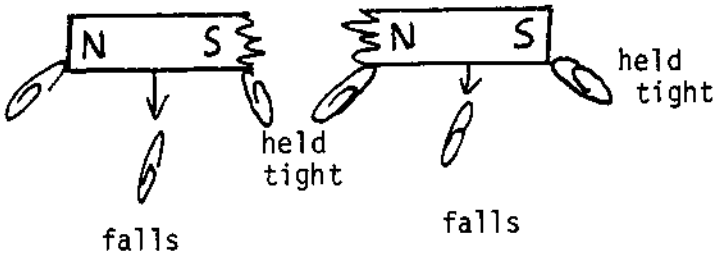
EXPERIMENT 11.7. The concentration of field in a magnet.

Materials: Magnet, paper clips.

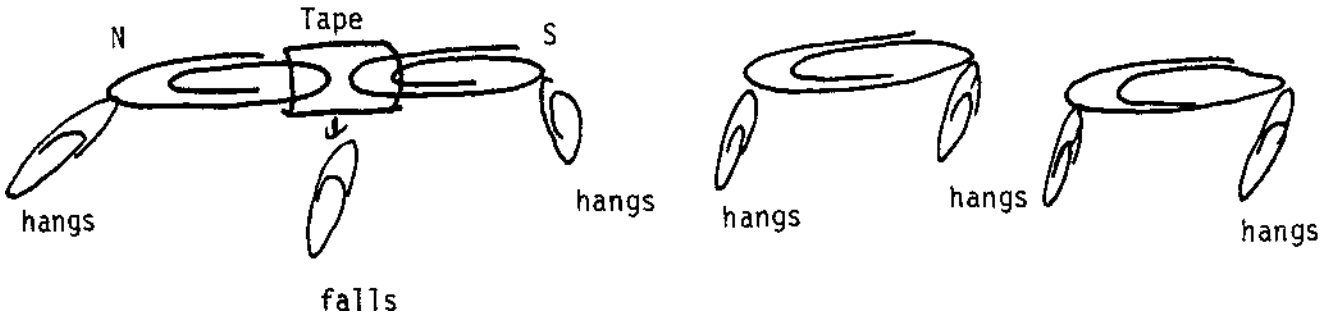
Procedure: Try to hang paper clips at different points along the magnet. whether it is a horse shoe or a bar. Where do the clips hang tightest? Where do they fall off? The field is concentrated at the ends of the magnet.



If you could break the magnet, you would find the field still concentrated at the two ends.



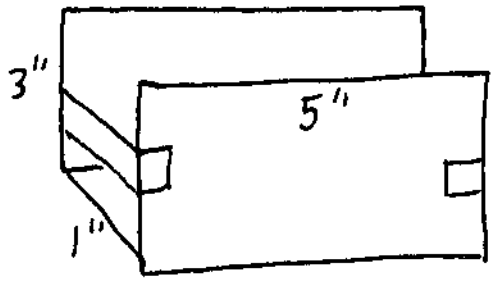
You may check this roughly by magnetizing two paper clips by stroking, and connecting them end to end, then try hanging a third, unmagnetized paper clip from them. It will only hang at the ends, but when the two are separated, it will hang from all four ends.



EXPERIMENT 11.8. The dip circle.

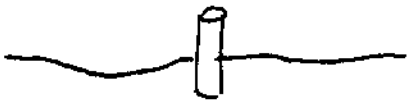
Materials: Paper clip, straw, piece of card, tape.

Procedure: Cut and fold the card (thick paper will do) as shown:

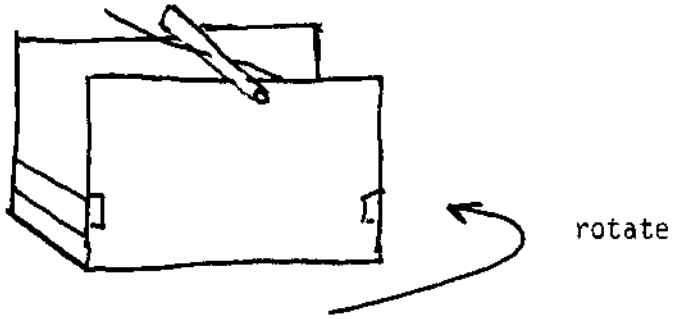


Unfold a paper clip, and magnetize by stroking.

Push the clip through a piece of soda straw two inches long.

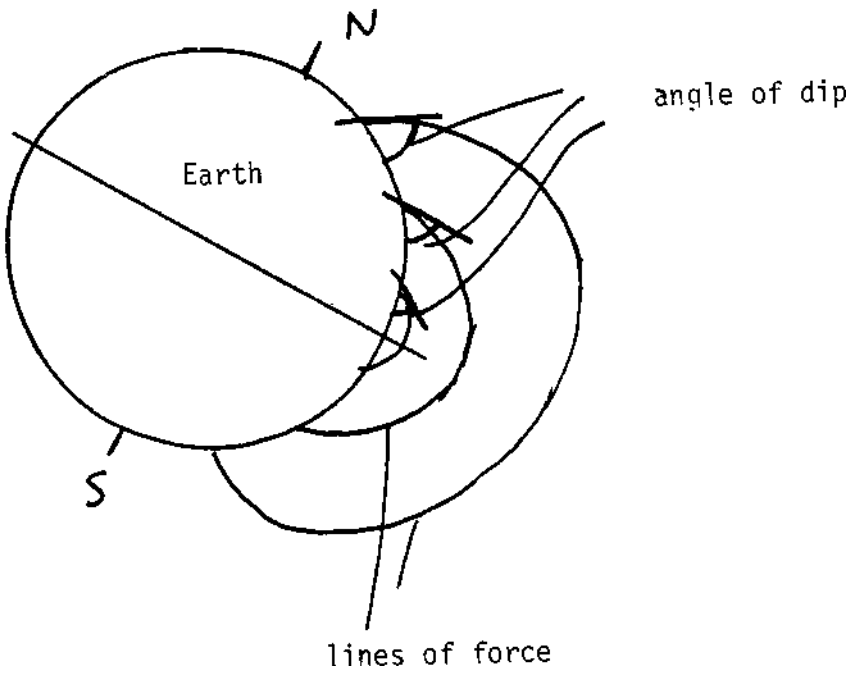


Adjust the clip so that it appears as balanced and symmetrical as possible. Place it on the stand.



Rotate the stand on a table. The maximum angle of dip of the arrangement occurs when the wire points N.S. Measure this angle roughly. Rotate the device 180° and do the same thing. The clip needle must be carefully balanced when pointing E.W. to obtain accurate results.

How does the angle of dip correspond to the latitude? 11.08



EXPERIMENT 11.9. What is magnetic?

Materials: magnets

Procedure: Find out what materials are magnetic by experimentally seeing which are attracted by the magnet. Try various coins, metal objects such as desks and shelves, knives, wooden and plastic objects. Make a list of the materials and whether they are magnetic or not. How many magnetic materials did you find?

Experiment 11.10. Penetration of magnetism

Materials: magnet, paper clip, various materials.

Procedure: Place sheets of different materials (paper, wood, iron or steel sheet from a desk drawer on stool) between the magnet and the paper clip. Which materials reduce the magnet's power, and therefore the ability of the magnetic field to penetrate? Make allowance for the thickness of the sheet of material.

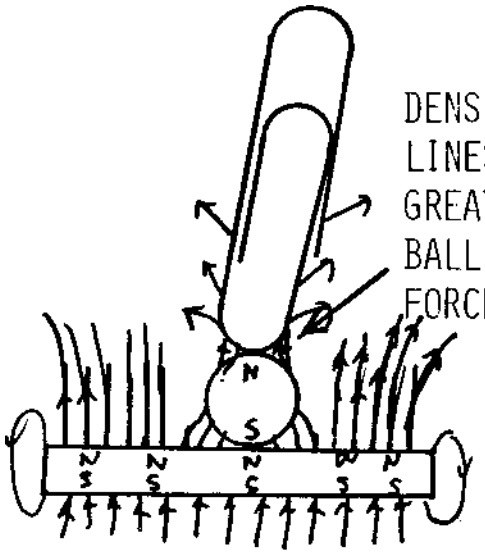
You will find magnetism penetrates most materials except for those capable of magnetization themselves, such as steel sheeting. This is because they become magnetised in such a direction as to oppose the field.

Experiment 11.11 - The Mysterious Magnet

Take a small magnet, such as are used to hold papers to metal walls or the refrigerator, (1" x $\frac{3}{4}$" x $\frac{3}{16}$" is suitable) many of these have a $\frac{3}{16}$" hole, through the center of the flat face, which is good. Now, place a small ball bearing (about $\frac{1}{4}$" diameter) at the center (resting in the hole, if there is one). (If no ball is available, simply fold a paper clip as shown in the figure). Bring up an unmagnetized paper clip, as shown, touch it to the top of the ball and raise it. Will the ball bearing stick to the magnet or the clip? Most people would think it would stick to the magnet, but in fact, the bearing rises nicely with the paper clip. How does this mysterious event occur? We tend to think that it is the power of the field of the magnet which will cause an object to be attracted - but, for an induced magnet as with the ball bearing, it is the gradient of the field. To see this, imagine the bearing placed in a uniform field, no matter how strong - the induced poles are equal and opposite at each end, so there is no net force. Back to our little ball. The magnets holding papers to walls are magnetized with the poles on the flat faces - so the lines of force are emitted more at less uniformly from this surface as shown. These converge on the ball bearing, and even more on the paper clip, as shown - so the induced poles on the top of the ball bearing and paper clip are very large - causing the ball bearing to rise. If, now, you put the ball or folded paper clip against the edge of the magnet, as shown in the last figure, it will be impossible to remove with a paper clip, as previously, because the lines of force now go from one pole to the other through the ball or folded paper clip, without going through the other clip at all.

Arthur Schmidt , Physics Teacher, 23, 375 (1985).

John Ecklin, Physics Teacher, 25, 73 (1987).



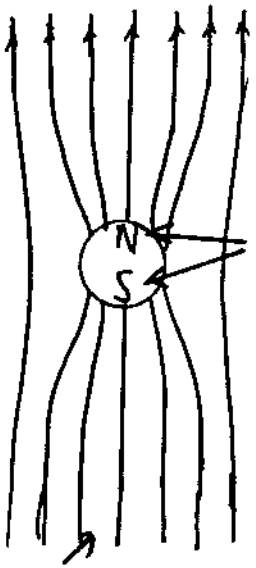
DENSITY OF LINES OF FORCE GREATER BETWEEN BALL AND CLIP, SO FORCE GREATER

PAPER CLIP

BALL BEARING

MAGNET

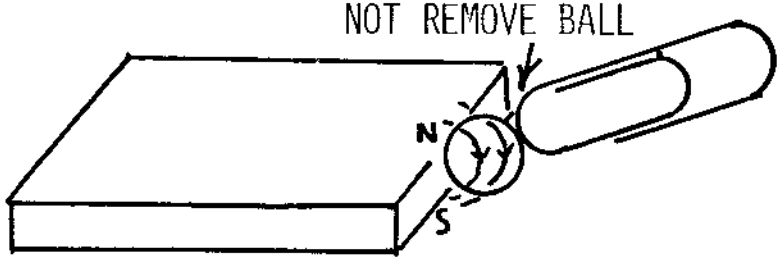
BALL MAY BE REPLACED BY FOLDED PAPER CLIP



POLES EQUALLY STRONG - NO MOTION

UNIFORM FIELD

IN THIS POSITION PAPER CLIP WILL NOT REMOVE BALL



INTRODUCTION TO SECTION 12

Experiments in Electricity

It is impossible to employ the same simple equipment for experiments in electricity as it is for mechanics, heat and light, for example.

The primary requirement is a source of D.C. Batteries are most commonly used, but are a poor idea, since, from one semester to the next, new batteries must be found, the old ones having died on the shelf. It follows, a power supply running off the 120V A.C. is much preferable.

The most suitable source we have come across is a model electric train supply. The HO gauge power supply provides D.C., variable from 0-12V, costing about $10.00. It has an overload button, and is practically indestructable. It can be used indefinitely, and cannot be drained flat. (Anything made to be used by ten year old kids must be virtually indestructible)

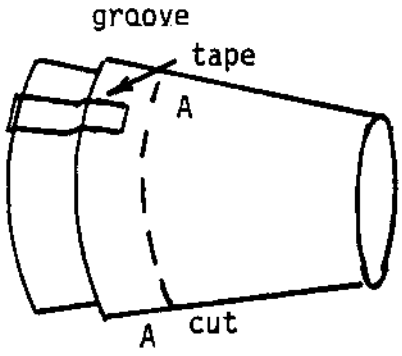
The second requirement is a source of insulated copper wire. Again, this can be purchased, but the heavy-current windings of a transformer, the motor of an old toy, any of these can be employed. Note:- #26 insulated wire is good .

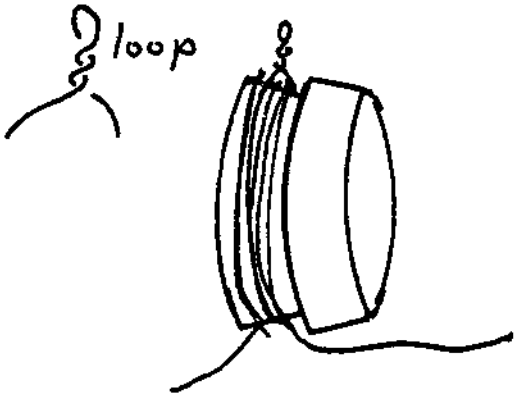
The fundamental D.C. experiments concern the relationship between current and magnetism, and between potential and current, resistance, and inductance.

Experiment 12-1. The Magnetic Field Around a Coil of Wire

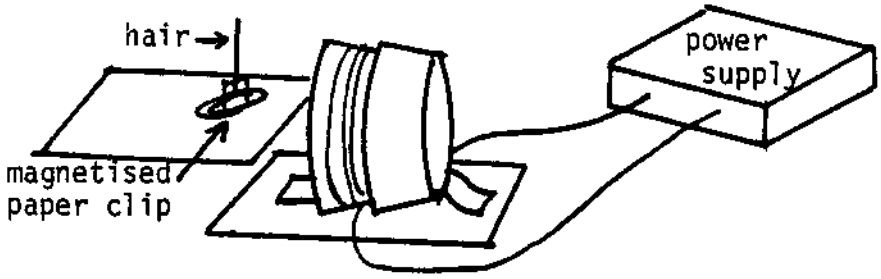
Materials: Dixie cups, copper wire (#26 insulated works well), paper clips, magnet, a fine thread or a hair, HO model train power supply.

Procedure: Place two cups, one inside the other, and tape them together over the lip, as shown:





Now wind twenty turns of wire around the inner cup, in the groove, form a loop, as shown and continue to wind eighty more turns, fastening the coil in place with tape. Clean the ends of the wire and the loop by scraping with the scissors blade. Cut the cups along AA to form a coil of wire, and attach to the D.C. terminals of the power supply. Tape the coil, as shown, to a piece of card on the table. Place a sheet of paper on a book to come half

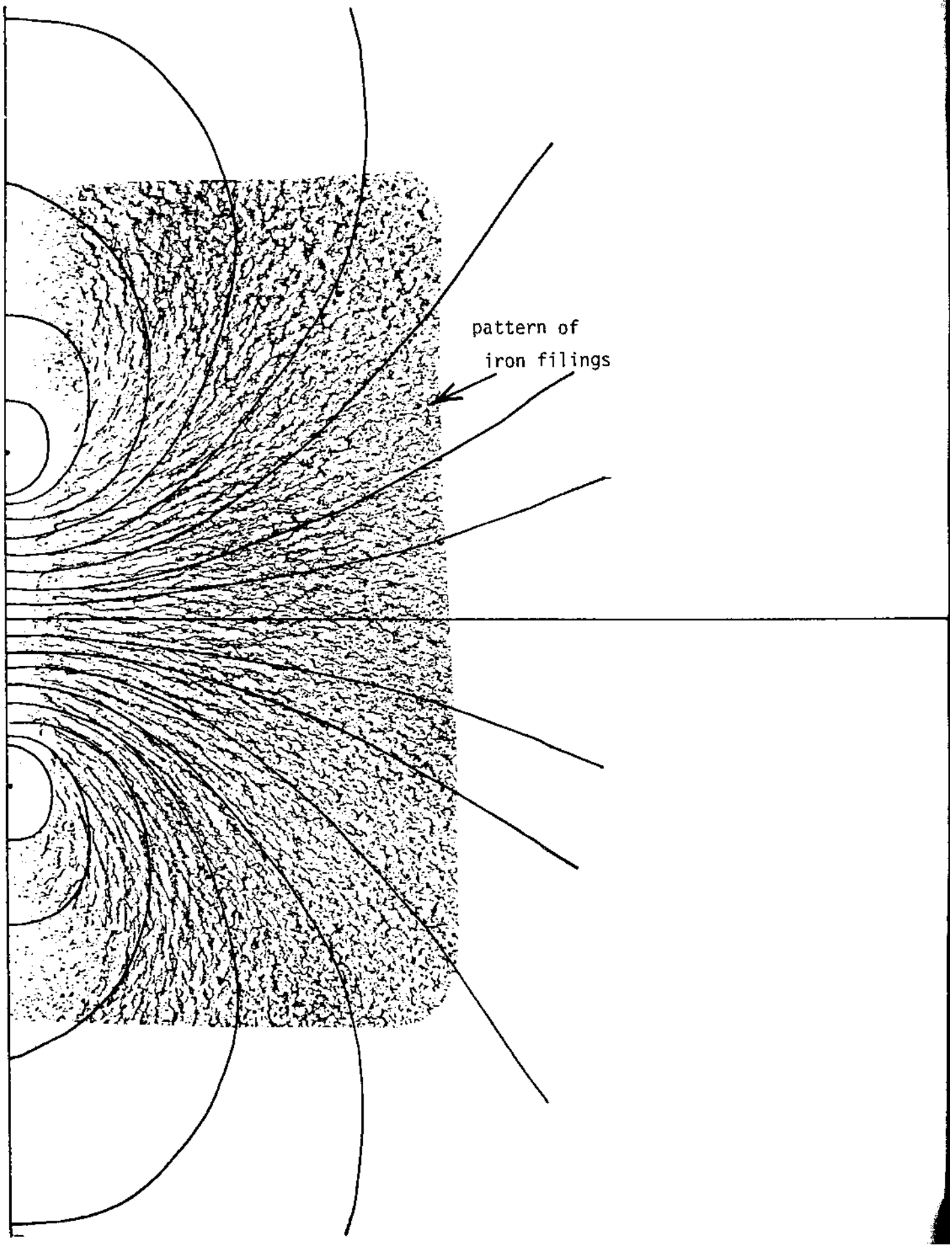


way up the coil. Now, map the field, as was done for the bar magnet (experiment 11.03) using the magnetized paper clip. The lines of force of the field are shown overpage. Do they agree with your results?

1. Increase and decrease the current. Are the lines of force dependent on the current? They should not be. The strength of the field depends on the current, but the direction of the lines of force, solely on the geometry.

2. Pass the current through the twenty turns, as well as through the 100 turns. Does the field change? Again, the number of turns should affect the magnitude, not the direction of the field.

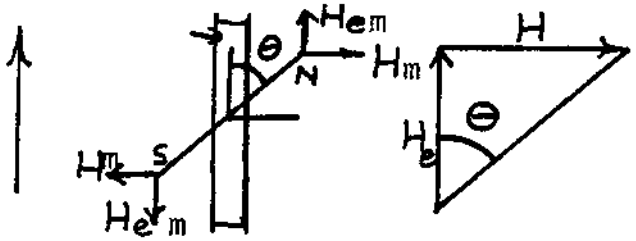
3. Do the lines of force form complete loops? Trace one all the way round the coil to ensure that they do, unlike the bar magnet, where they run from the north pole to the south pole, outside the magnet.


pattern of
iron filings

Experiment 12.2 The Tangent Galvanometer

Materials: Power supply, insulated copper, wire, paper clips, string, cardboard, tape, one long human hair.

Procedure: The simplest sensitive current measuring device one can construct is the tangent galvanometer. This compares the torque on a small magnet of pole strength m produced by the field H provided by a current carrying coil, with the torque provided by the earth's magnetic field H_e as shown



A stable equilibrium exists when

$$mH = mH_e \tan \theta$$

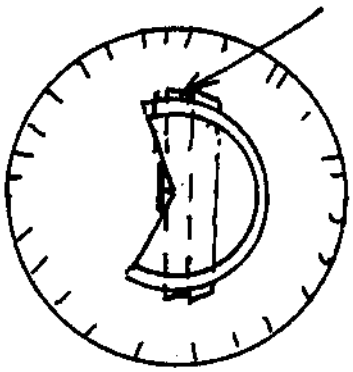
where θ is the angle of rotation of the magnet. It follows that $H \propto \tan \theta$ and since if i is the current through the coil

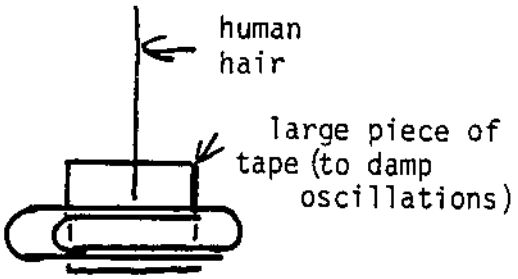
$$i \propto H \propto \tan \theta$$

For small angles (less than 10°) approximately

$$i \propto \theta$$

Take the coil of wire used in experiment 12-1, and tape it over the dial shown



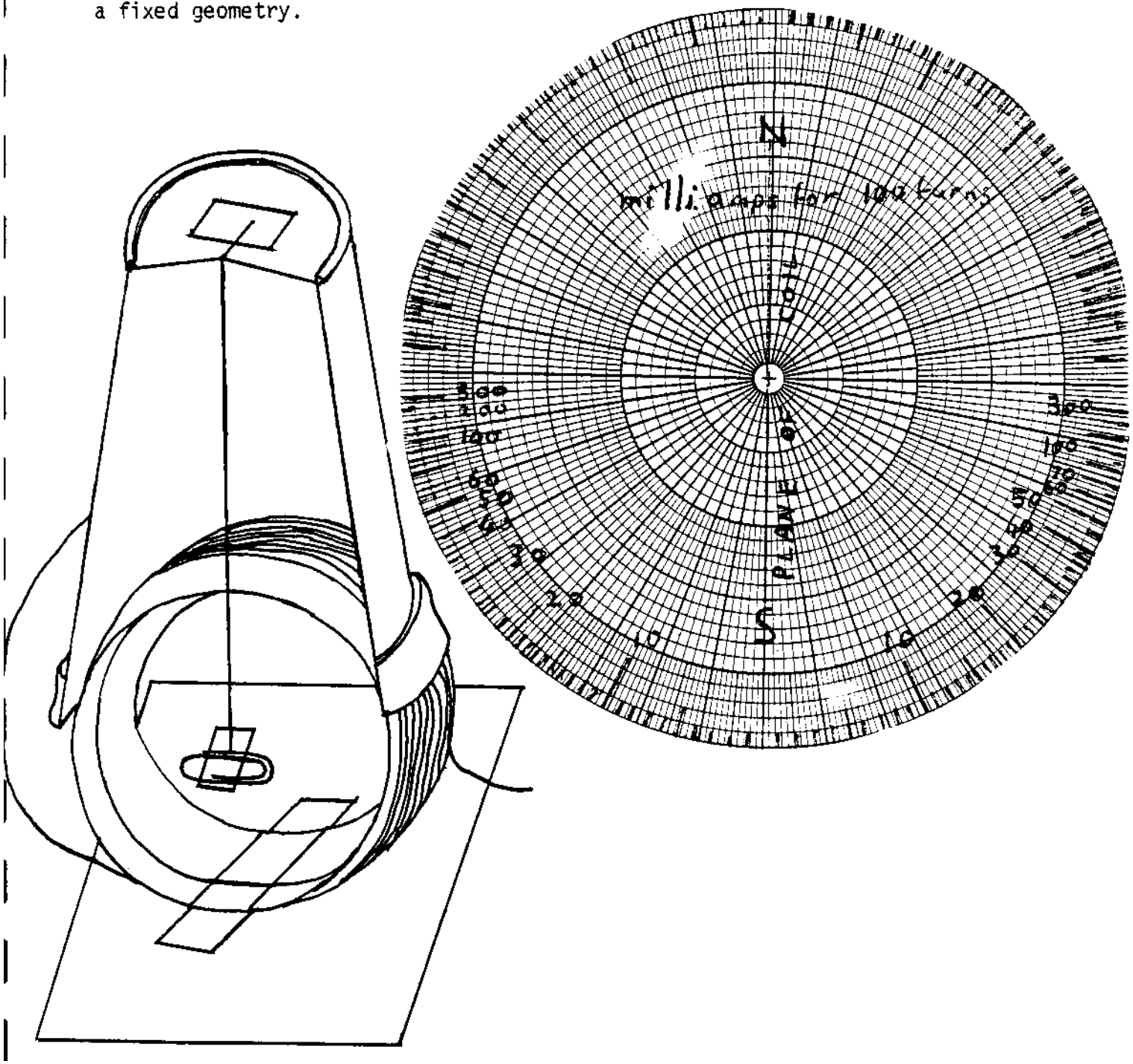


Now, cut a paper cup to fit over the coil, and support a magnetized paper clip by a hair to lie at the center of the coil, as shown. The paper clip should swing freely, and align itself with the earth's field, which is parallel to the face of the coil. The tripod from experiment 1-34 may be used in place of the cup to support the paper clip.

Pass a current through the coil from the power supply and notice the deflection of the paper clip. You can read the value of the current in this way.

You may vary the voltage supplied to the meter by using the control on the power supply. However, it may not be possible to reduce the current sufficiently to be read, even when only twenty turns of the coil are used. A resistance, as described in 12.3, must then be placed in the circuit.

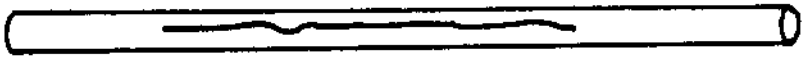
Notice that, since we are comparing the current with the earth's field, which is sensibly constant, we build a calibrated meter by simply using a fixed geometry.



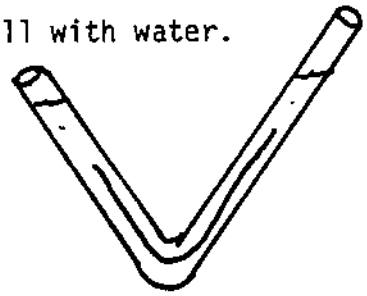
Experiment 12.3 Electrical Resistance, (series and parallel)

Materials: straws, paper clips, galvanometer, power supply, pencils.

Procedure: 1) Resistance of a conducting fluid: straighten a paper clip and push in to the center of a straw, using another clip.

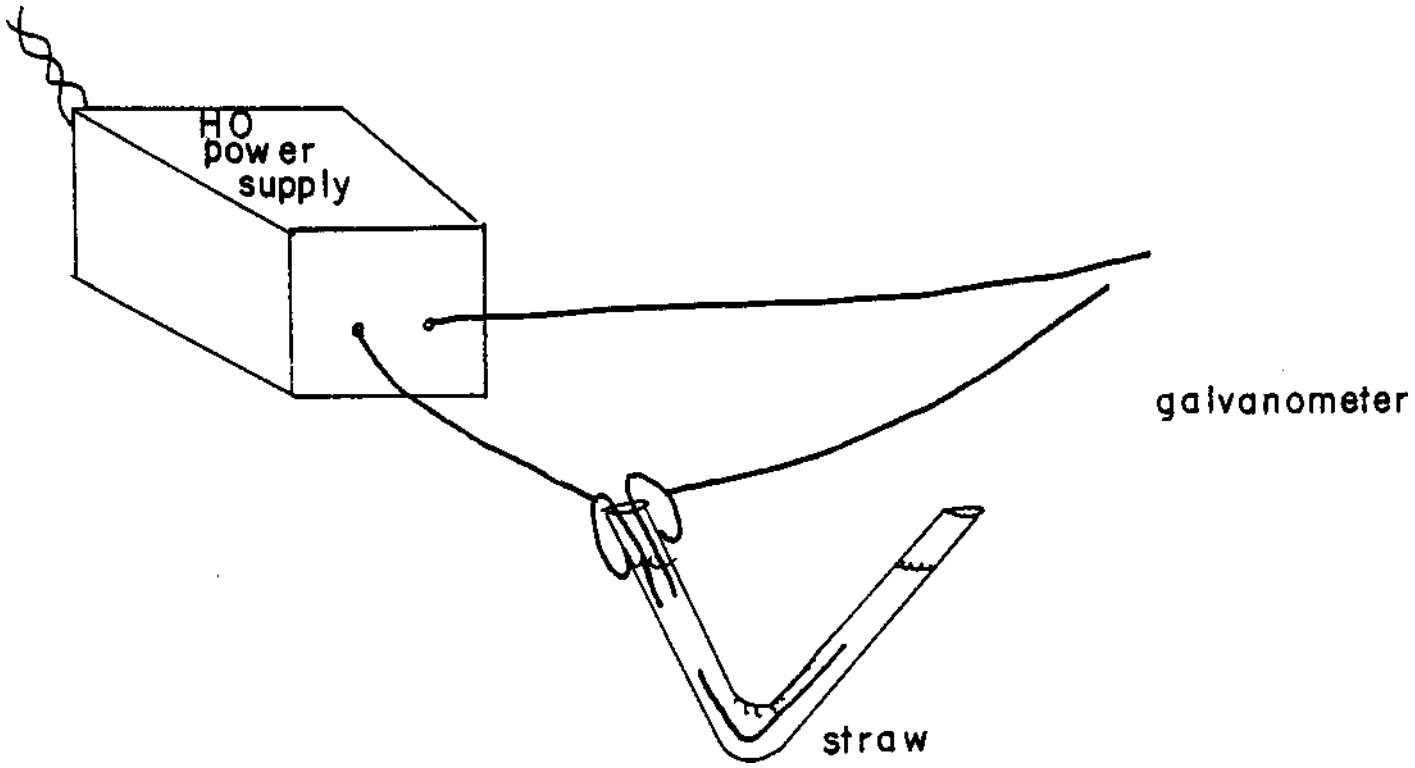


Bend the straw, and fill with water.



Straighten the large end of two paper clips: Put the two clips on the opposite sides of one end of the straw:

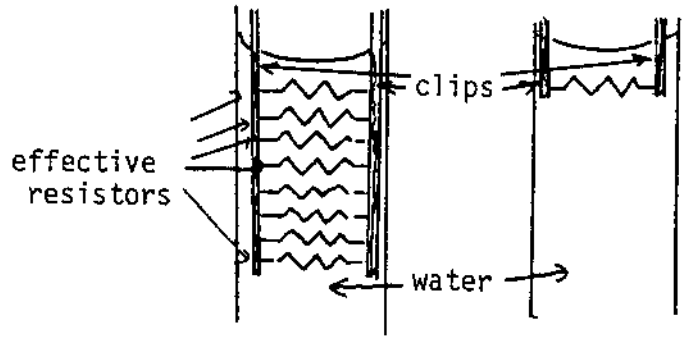
Connect the two clips between the power supply and the galvanometer.



The resistance of the water now determines the current through the galvanometer. Measure the current, versus the length of the paper clip immersed in the water,

The resistance of the water is inversely proportional the length of the clip immersed--this is a parallel circuit.

To see why this is a parallel circuit, imagine each small length of one clip which is immersed has aresistance - provided by the water, between it and the corresponding part of the other clip, as shown. As the clips dip deeper into the water, more and more of the resistors will come into play. Since each runs directly from one clip to the other, they are connected in parallel.

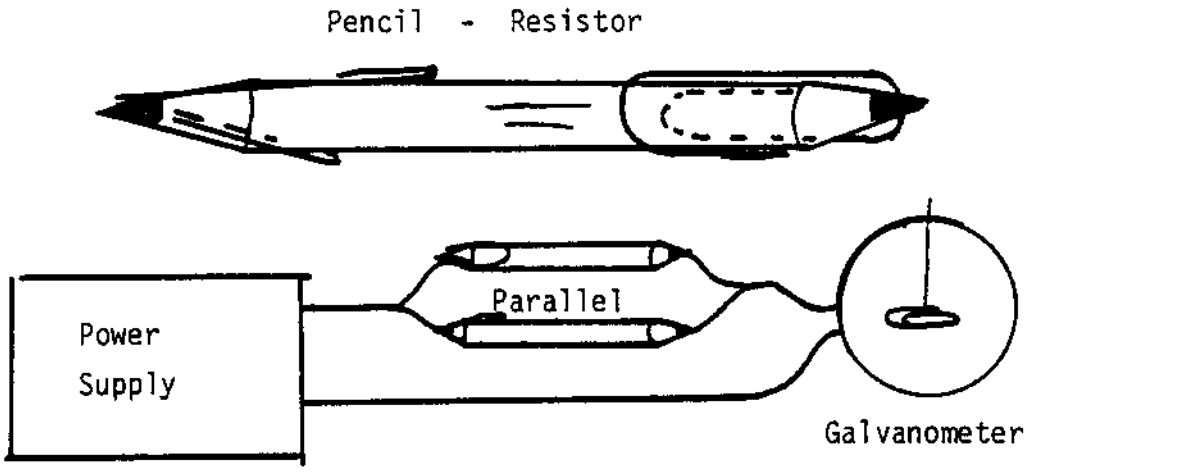


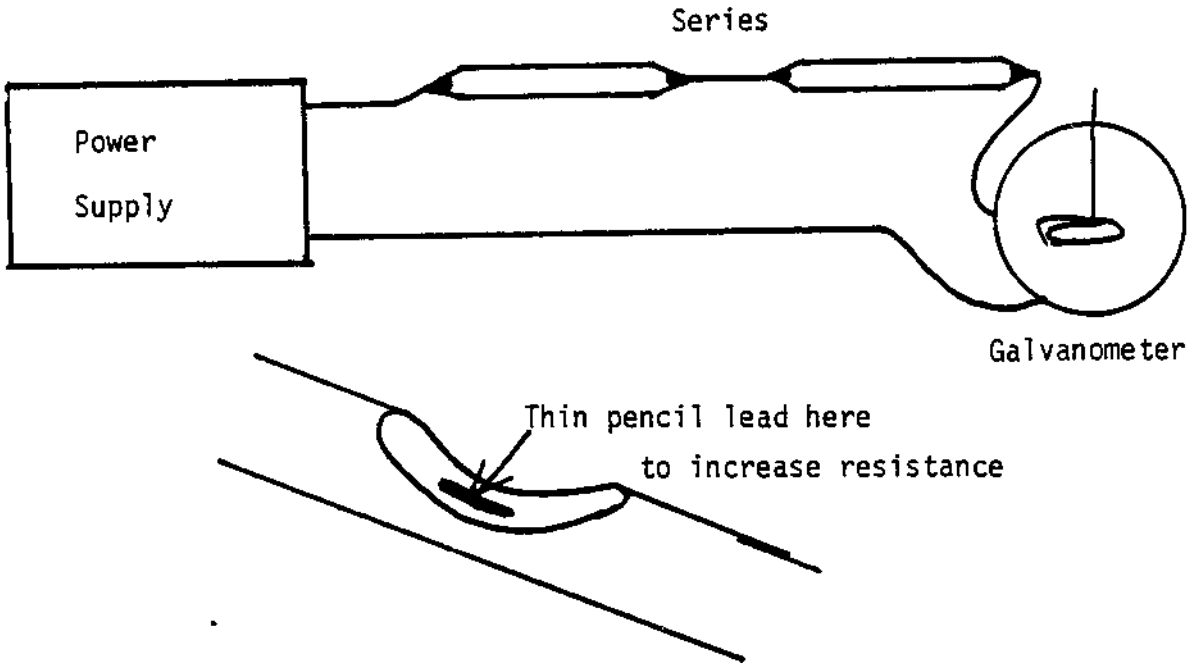
You should find the current is proportional to the voltage supplied by the power supply, divided by the resistance of the water. This ratio, in turn, is proportional to the length of the clip immersed, i.e. in a parallel circuit, the resistance is proportional to the reciprocal of the length immersed. Since, if the nth millimeter immersed presents a resistance R_n, the total resistance is not $R = R_1 + R_2 + R_3 + \ldots . R_n$

but $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots . \frac{1}{R_n}$

2) Series and Parallel Circuits: A series circuit is one in which the same current passes successively through several resistances. Commercial resistances of from 100 to 500 ohms are suitable for this purpose. The power supply, when full on, delivers an approximately constant voltage, and the current is measured by the galvanometer. If no commercial resistances are available, some interesting experiments can be performed using pencils.

A pencil is broken in half, and both ends of the two pieces sharpened. It is necessary to make a good connection to the two ends, which may be done using paper clips, as shown, and the variation of current through the galvanometer studied putting the two pencils first in series, and then in parallel. The current in series should be about a quarter of that in parallel. Is it? Explain why. A pencil used in this way has a resistance of about 20 ohms, which is rather low, so a long pencil should be used. Its resistance can be increased by cutting into the lead with a pen knife or pair of scissors.

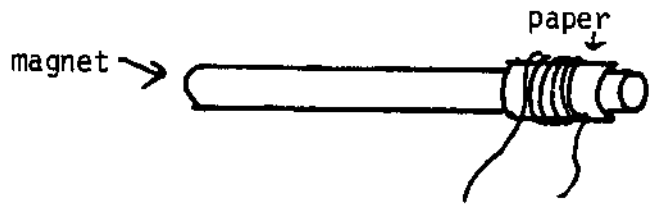

Pencil - Resistor
Parallel
Power
Supply
Galvanometer


Series
Power
Supply
Galvanometer
Thin pencil lead here
to increase resistance

Experiment 12.4 Magnetic Induction

Materials: Copper wire, magnet, galvanometer

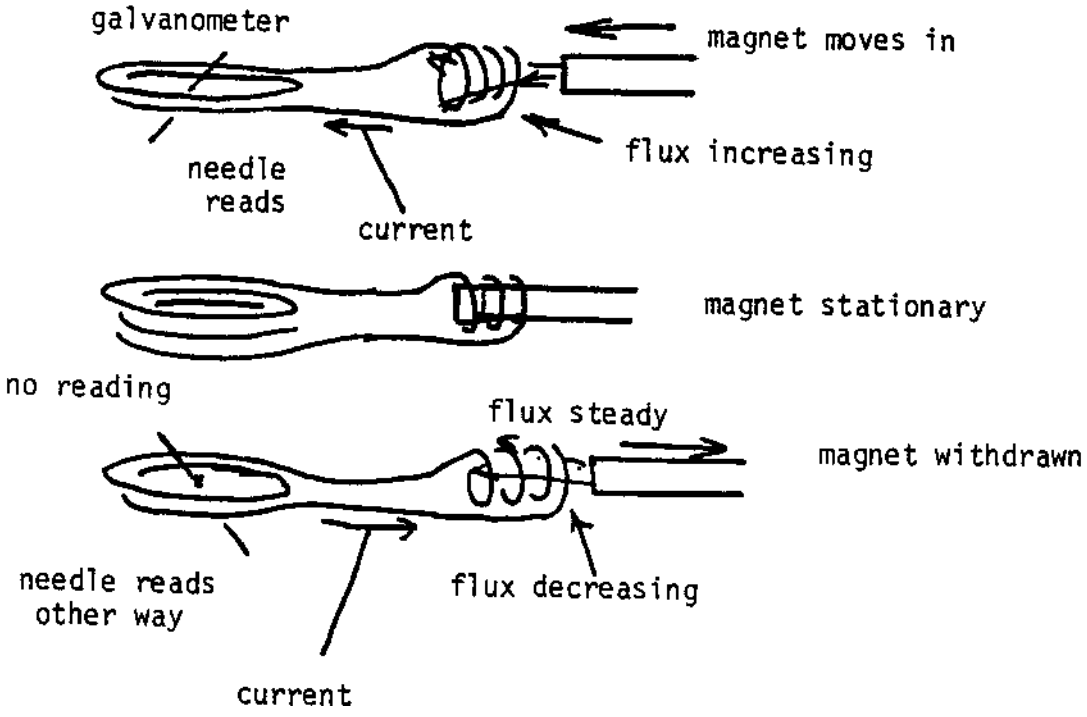
Procedure: Wind a coil of one hundred turns on a small paper tube, formed by rolling a sheet of paper around the magnet pole, and taping the ends.



Scrape the ends of the coil clean and attach to the galvanometer. Rapidly remove the magnet from the paper roll. Which way does the galvanometer pointer move? Rapidly replace the magnet. Again which way does it deflect? Move the magnet to and fro, some distance from the coil. Does the pointer move?

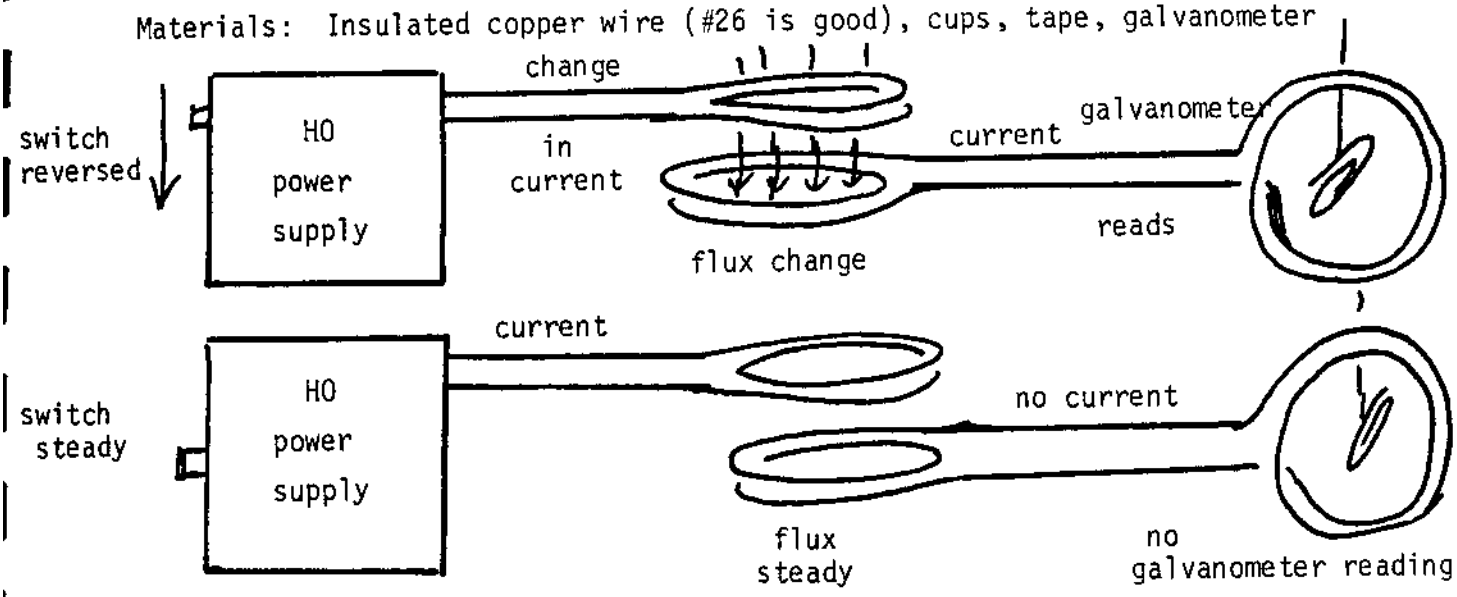
The changing magnetic field induces an electromotive force in the coil which causes a current to flow through the galvanometer. Make sure the leads from the galvanometer are sufficiently long for the magnet not to affect it.

The deflection of the galvanometer is a measure of the change in magnetic flux passing through the little coil, and we can use this device as a flux meter. It only measures the flux accurately if the coil is moved in less time than it takes for the paper clip pointer to move very far. Under these circumstances, the change in flux is proportional to $(1 - \cos\theta)$ where θ is the deflection, or approximately proportion to θ^2, if θ is small.



Experiment 12.5 Mutual Inductance

Materials: Insulated copper wire (#26 is good), cups, tape, galvanometer



Procedure: Wind one hundred turns of wire on two cups, as described in experiment 12.1. Wind a second coil of twenty turns on a second pair of cups, make a loop, and wind eighty more turns. Scrape the ends of the two coils, and loop. Connect one to the DC on the power supply, and the second to the galvanometer. Place the two coils face to face, as close as possible. Now, turn the reversing switch on the power supply, and notice how the galvanometer responds, swinging to a certain angle, before returning to zero. The maximum deflection of the galvanometer corresponds to the pulse of charge flowing through it. The galvanometer responds to the charge rather than the current. Used in this way, it is called a ballistic galvanometer, and the deflection depends upon the charge.

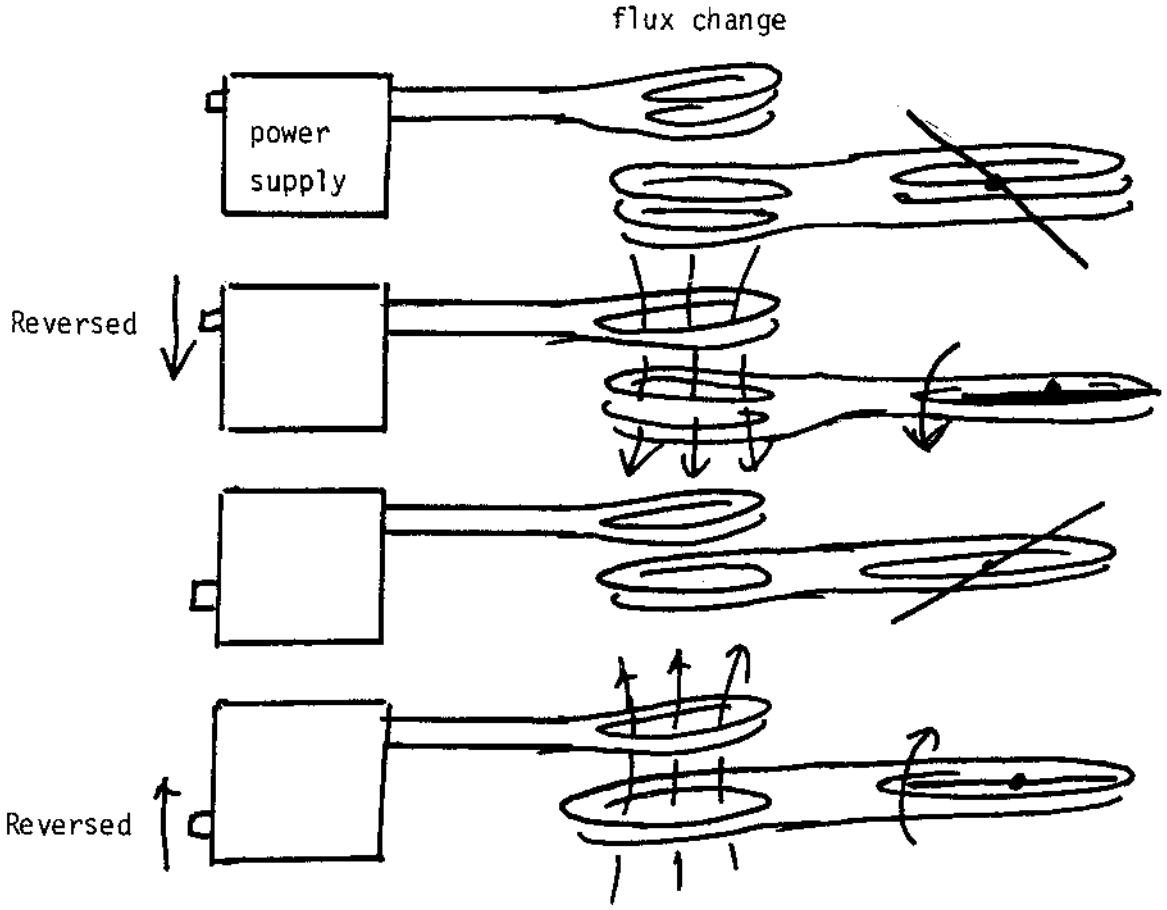
On reversing the switch, the magnetic field established by the first coil is reversed, and since the same field passes through the second coil, the reversal of the field induces an E.M.F. in the second coil, which in turn induces a current in the galvanometer coil. Reverse the power supply switch the other way, and notice the deflection of the galvanometer is reversed. Now, separate the two coils, by about one radius and notice how the deflection is reduced on reversing the power supply, because the field looping the second coil is reduced.

Connect the power supply to the twenty turns at the loop instead of the hundred. On reversing the field, does the galvanometer deflection increase or decrease?

If the deflection of the galvanometer is too small to read with one reversal of the DC power supply, you can deliver a series of reversals to build up large oscillations of the galvanometer needle which can easily be seen. The principle is the same as delivering judicious pushes at the right time to a child's swing to build up large oscillations.

The needle should be set oscillating very slightly, then the switch reversed in the middle of each swing. The oscillations will either get larger, if the pulses are delivered in the right phase, or they will get smaller, if you are

reversing one way when you should be reversing the other. Each reversal reverses the flow through the secondary coil, and delivers one pulse to the needle. Try reversing one coil with respect to the other. You will find that the same procedure which made the oscillations grow larger now makes them grow smaller, showing the current is reversed. If the coils are separated by a radius, it will take many more reversals to make the oscillations grow, since the flux change is smaller.



EXPERIMENT 12.6 Electrolysis

Materials: power supply, insulated copper wire, straws, paper clips, water, aluminum foil

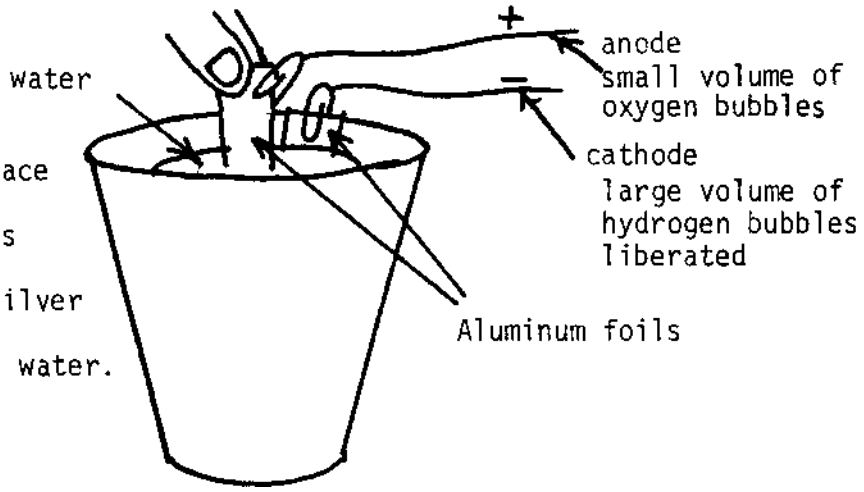
Procedure: When an electric current is passed through water, hydrogen is liberated at the negative terminal and oxygen at the positive.

$$4H_2O \rightarrow 4(H^+ + OH^-) \rightarrow \begin{matrix} 4H^+ + 4 \text{ electrons} \rightarrow 2H_2 \\ 4(OH)^- - 4 \text{ electrons} \rightarrow O_2 + 2H_2O \end{matrix}$$

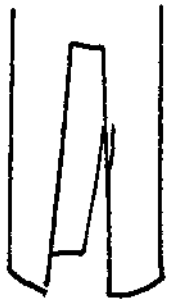
Hence there should be twice the volume of hydrogen liberated as oxygen. Most metal cathodes are oxidised, and hence no oxygen is released, only rare metals such as platin um not being attacked. Aluminum, however, forms a thin, insoluble oxide coating, and, once formed, it protects the metal beneath.

Cut two pieces of aluminum foil about one inch by three inches. Fasten one to the inside of a cup filled with water using a paper clip. Attach this to the power supply using copper wire with the ends scraped clean. Fasten the other foil, using a paper clip and wire, to the other pole of the power supply, and turn it on. Submerge the foil in the water, as close to the other foil as possible without touching. Note bubbles form rapidly on one foil, and more slowly on the other. They form rapidly on the cathode, where hydrogen is released, and the oxygen bubbles form more slowly on the anode, since only half as much oxygen as hydogen is liberated.

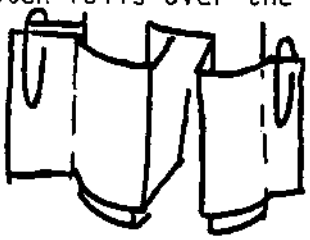
Better still, you can use quarters in place of the aluminum foil as electrodes since the silver is not attacked by the water.



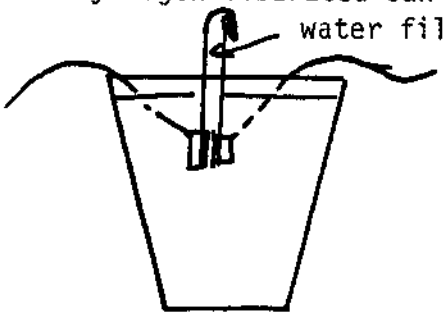
Cut the bottom end of a straw, as shown



Fasten foils over the piece cut-out, using paper clips. Submerge



in the cup of water, suck up water to fill the straw, fold over the end and tape shut, as shown. Connect to the power supply. The oxygen and hydrogen liberated can be collected together.



Light a match, and hold over the end of the straw as it is opened. A flame, or slight pop should result from the explosive mixture of oxygen and hydrogen.

Replace the aluminum electrodes by placing bare copper wire in the water. Note hydrogen is given off, but no oxygen-----instead copper oxide is formed. If paper clips are used for the electrodes, a brown discoloration of the water results from the anode, of what is probably iron oxide or hydroxide.

A simple experiment is to place two bare aluminum electrodes close together in soapy water. A match applied to the bubbles makes a nice pop.

EXPERIMENT 12.6 Electrolysis

Materials: power supply, insulated copper wire, straws, paper clips, water, aluminum foil

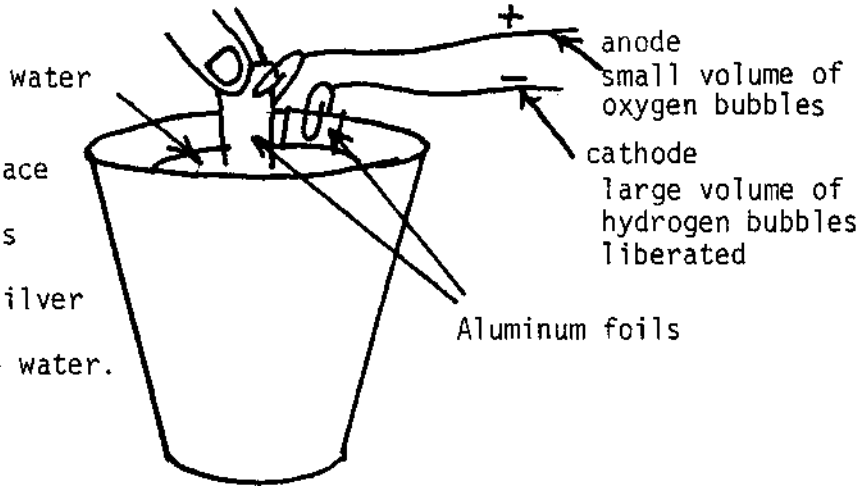
Procedure: When an electric current is passed through water, hydrogen is liberated at the negative terminal and oxygen at the positive.

$$4H_2O \rightarrow 4(H^+ + OH^-) \rightarrow \begin{matrix} 4H^+ + 4 \text{ electrons} \rightarrow 2H_2 \\ 4(OH)^- - 4 \text{ electrons} \rightarrow O_2 + 2H_2O \end{matrix}$$

Hence there should be twice the volume of hydrogen liberated as oxygen. Most metal cathodes are oxidised, and hence no oxygen is released, only rare metals such as platin um not being attacked. Aluminum, however, forms a thin, insoluble oxide coating, and, once formed, it protects the metal beneath.

Cut two pieces of aluminum foil about one inch by three inches. Fasten one to the inside of a cup filled with water using a paper clip. Attach this to the power supply using copper wire with the ends scraped clean. Fasten the other foil, using a paper clip and wire, to the other pole of the power supply, and turn it on. Submerge the foil in the water, as close to the other foil as possible without touching. Note bubbles form rapidly on one foil, and more slowly on the other. They form rapidly on the cathode, where hydrogen is released, and the oxygen bubbles form more slowly on the anode, since only half as much oxygen as hydogen is liberated.

Better still, you can use quarters in place of the aluminum foil as electrodes since the silver is not attacked by the water.



EXPERIMENT 12.07. Forces between parallel conductors

Materials: This experiment needs no wire! --Only aluminum foil and a battery or other current source.

Method: Now for a simple experiment to show that currents in the same direction attract, and in the opposite direction, repel. Cut a strip about 1 cm wide and 70 cm long from a roll of thin household aluminum foil. Fold it in the middle, and tape the two ends to the edge of a table, as shown in Fig. 1, then run the fingers down the two adjacent parts of the strip to bring them as close together as possible without touching. Cut two more pieces of foil to connect the ends attached to the table to the opposite sides of a battery or power supply. As the connection is made, the two parts of the strip will repel and move apart slightly, since they carry current in opposite directions.

For a large audience, the strip can be folded and laid loosely across an overhead projector, taping the ends of the strip to the edge of the projection plate. The motion is not as large, because of friction with the transparent plate, but the magnification makes it easily visible. To show that currents in the same direction attract, the top ends of the folded strip are taped together and attached to one terminal of the supply, and the fold at the bottom end attached by a separate foil strip to the other terminal of the supply. This time, the two parts of the strip will move together as shown. It is possible to use either a d.c. or a.c. supply in this experiment, but connecting directly across the 110 V supply is definitely not recommended--you will either blow a fuse or melt the aluminum!

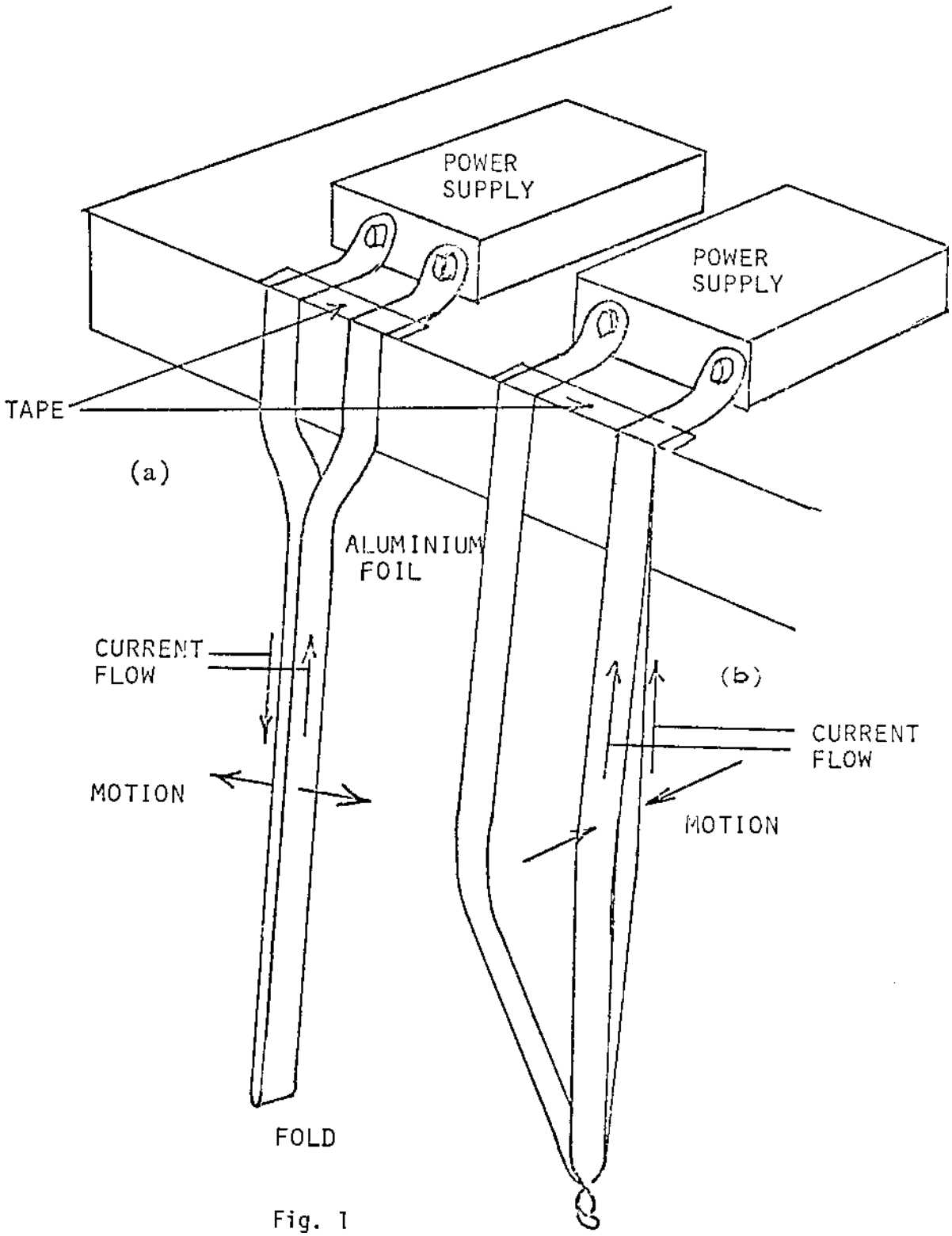
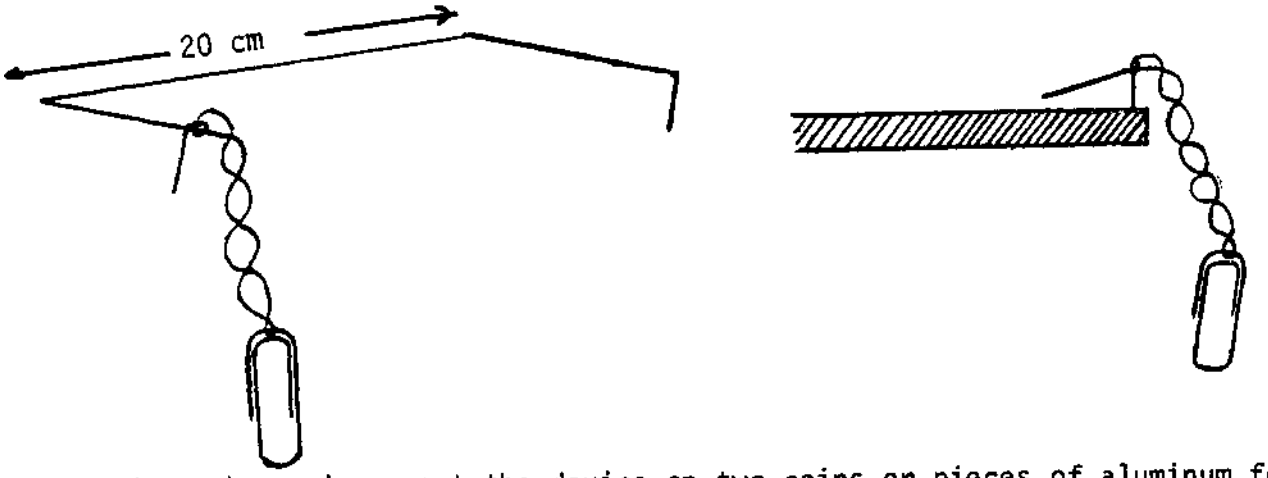

POWER SUPPLY
POWER SUPPLY
TAPE
(a)
ALUMINIUM FOIL
CURRENT FLOW
MOTION
FOLD
(b)
CURRENT FLOW
MOTION

Fig. 1

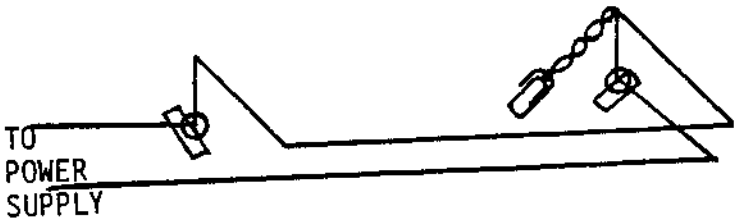
Experiment 12.08 The Current Balance

Materials: #26 copper wire, aluminum foil, or two coins, HO power supply, paper clip.

Procedure: Bend a piece of copper wire 40 cm long to the shape shown. This is the moving portion of the balance. A paper clip acts as a counter weight.



Clean the ends, and support the device on two coins or pieces of aluminum foil. A paper clip is used to attach one foil to a copper wire which runs under the conductor of the moving portion of the balance to the power supply. The other coin is attached to the other terminal of the supply.



Turn on the DC current and note the deflection of the wire . Since the circuits are opposed, there is a repulsion. It is difficult to get an accurate measurement with this device. The current must be read by a meter, and the balance calibrated by a standard weight, which could be a postage stamp, for example, noticing the weight giving the same deflection as the current.

Experiment 12.9. A Current Balance using a magnet

Materials: magnet wire, alnico magnet, straws, tape, needle.

Method: Here is a simple experiment designed by E. J. Wenham for the British Nuffield Physics course (Nuffield Physics Teachers' Guide, Year 1 and 2, Longmans 1978). It requires a small alnico magnet (about 1.2 cm long and .4 cm square) a drinking straw, a needle and a small channel made of card, such as the outside of a matchbox, to support the needle.

Fasten the magnet near to the end of the drinking straw with about 4 cm of sticky tape (cut to half width). See Fig. 1. Balance the straw across your finger to find its center of gravity, and stick the needle through the straw about 1 mm farther away from the magnet. Wind a coil of wire about 25 mm diameter with about 20 turns, and fix it with sticky tape to the table top close to the end of the channel, which is made by cutting the matchbox top so that it stands about 5 mm higher than the top of the coil. (Fig. 2).

Rest the drinking straw on the channel with the magnet on the axis of the coil.

Now cut about 2 cm of wire and bend it into a u to act as a counter-balancing rider on the straw. Use sticky tape to hold a second straw vertical just by the end of the balanced straw--and mark the position of the balance on it. If correctly connected into a series circuit with say, two 1.5 V cells and two 1.5 V lamps, the magnet will be pulled into the coil. When balance has been restored by sliding the rider along the straw, the current balance can be used to check whether or not the current is the same at all points in the circuit by connecting it between the lamp, between the cells, and between the cells and the lamps. This demonstration is very important in understanding current electricity. If a commercial ammeter is available the balance can be calibrated with a set of current markings made along the straw.

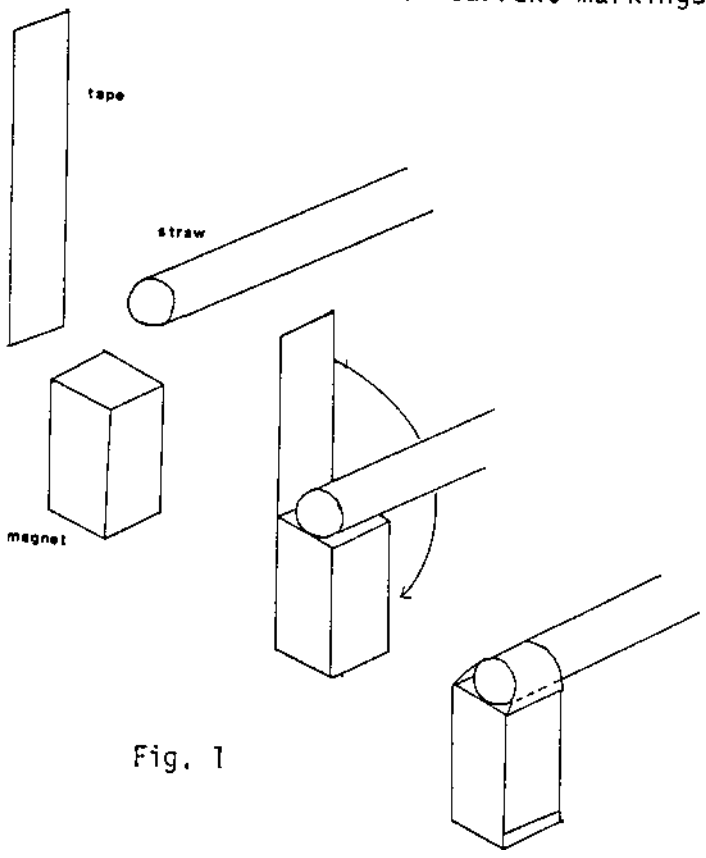


Fig. 1

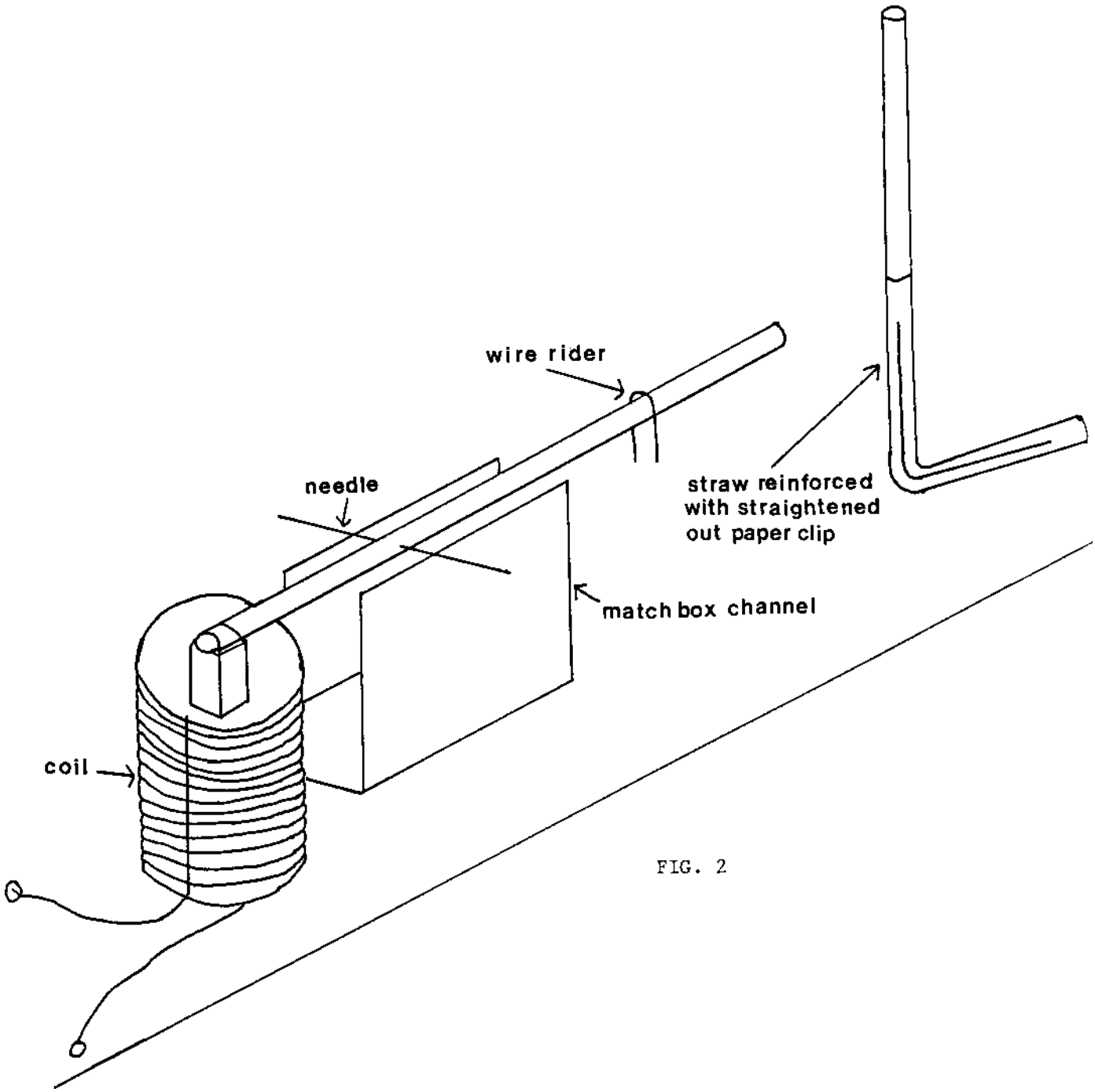
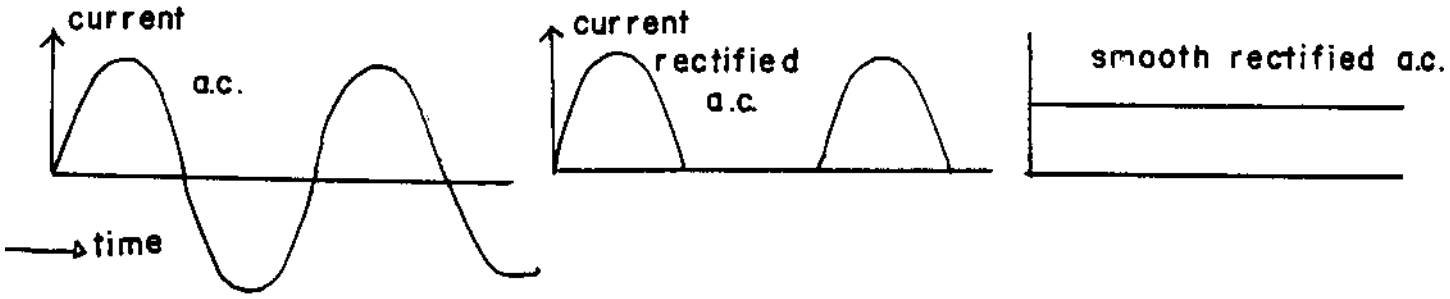

wire rider
needle
straw reinforced
with straightened
out paper clip
match box channel
coil

FIG. 2

Experiment 12.10 - A simple method of measuring alternating current, and the transformer.

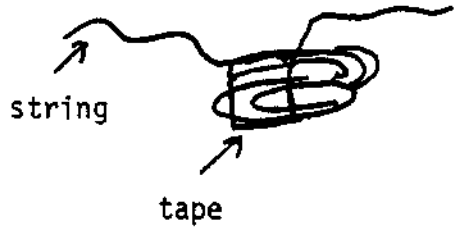
Materials: paper clips, string, thick paper, #26 insulated wire, HO power supply

Procedure: Alternating current (A.C.) such as is provided by the wall socket, cannot be measured using D.C. instruments, which read zero, the average value of the current. However, the current can be "rectified" by using a semiconduction device which allows current to flow in only one direction. Hence, such a device in series with the tangent galvanometer will allow it to read A.C.

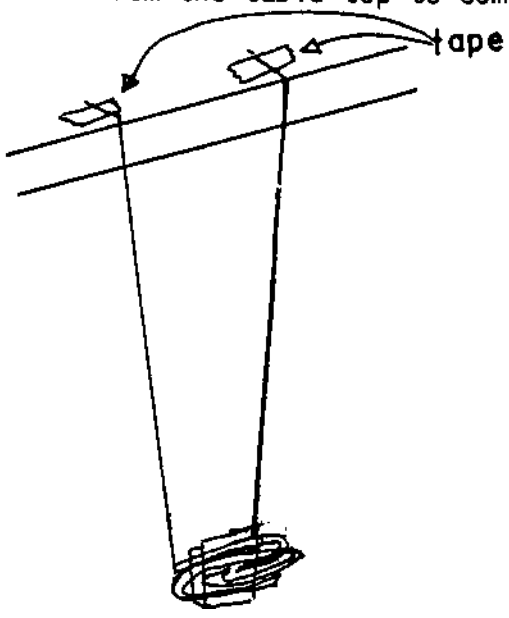


A very simple device for measuring A.C. currents uses a soft iron slug. The soft iron is not permanently magnetised, but the induced magnetisation from a nearby coil carrying the alternating current attracts it, causing it to move indicating the value of the current. We shall use unmagnetised paper clips in place of the slug.

Tape a piece of string to four paper clips, as shown.

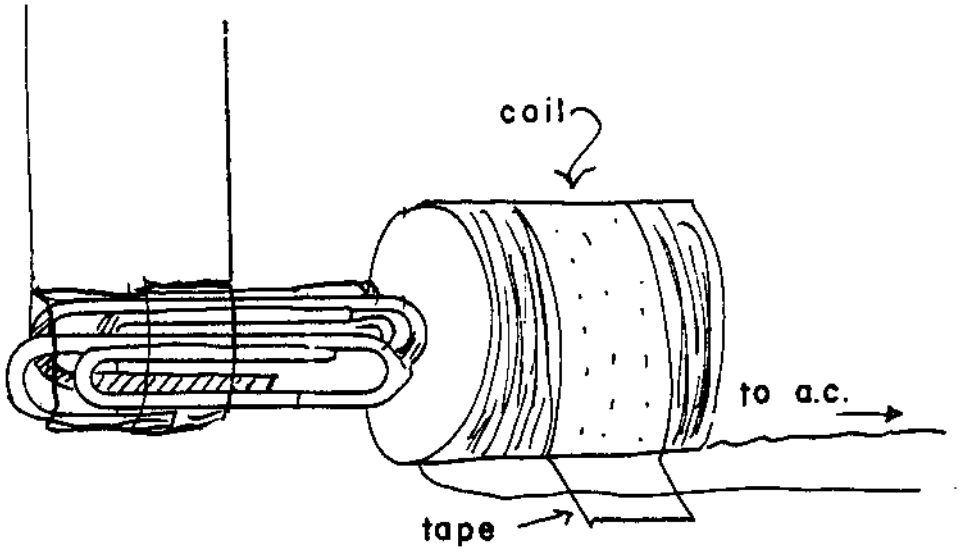


Hang this arrangement from the table top to come near the floor, using two pieces of tape.



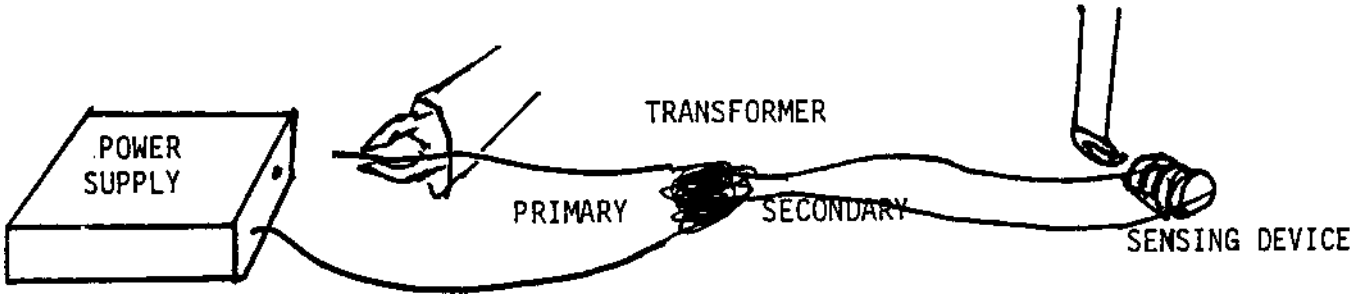
The height of the clip may be adjusted by pulling the string through the tape on the table top.

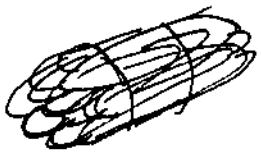
Now, roll a piece of card, or paper, into a cylinder large enough into which the four paper clips can slide easily, and wind a coil of 100 times on it. Place the cylinder on the floor, taping it so that the clip can slide in and out without twisting the sides. To check the device, connect the coil to the A.C. outlet of the power supply, and notice how the clips shoot into the coil.



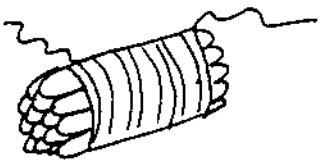
Now, to make a transformer, tape fifteen paper clips together. This will form the iron core of the transformer. Wind one hundred turns of wire on this. Tape up this coil. Now wind the secondary coil of one hundred turns on top of this, tape it down and wind a further one hundred turns on top. You can wrap a paper cylinder over the first hundred turns if you have difficulty in the turns sliding off the end of the coil.

Now, connect the one hundred turns of the secondary to the coil fastened to the floor, and fasten one end of the primary to one terminal of the 18 V A.C. outlet from the HO power supply. Observe the hung paper clip as you touch the other end to the other terminal. It will move, indicating that an A.C. current is induced in the secondary coil, passing through the detector coil also. Connect the second winding of the secondary in series with the first hundred turns. Note that, when connected so the turns oppose between the two secondary coils, i.e. are in opposite directions, no current is generated. With them in the same direction, this is not so--is the current larger, or smaller than with 100 turns? Why?

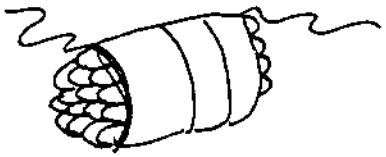




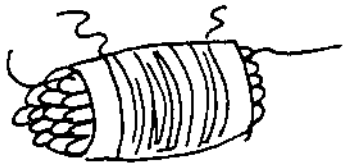
tape 15 paper clips together



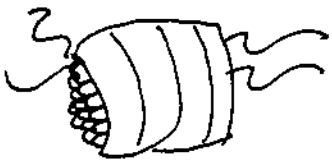
wind 100 turns



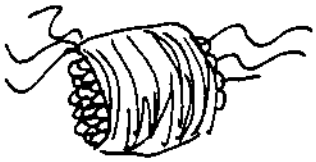
tape



wind 100 turns as secondary



tape again



wind extra 100 turns on secondary

In a transformer, the ratio of the currents in the primary, i_p, and secondary, i_s, is given approximately by

$$\frac{i_s}{i_p} = -\frac{n_p}{n_s} \qquad \text{for current circuits}$$

where n_p, n_s are the number of turns in the primary and secondary, respectively. The product of voltage and current is constant for both primary and secondary

$$V_p i_p = V_s i_s$$

so the voltage is given by

$$\frac{V_s}{V_p} = \frac{n_s}{n_p}$$

Now, our little coil measures the current in the circuit since the field in the coil is proportional to the current. Hence, excluding losses, the current is higher with fewer turns on the secondary, and the paper clip detecting device should move less, the more turns on the secondary.

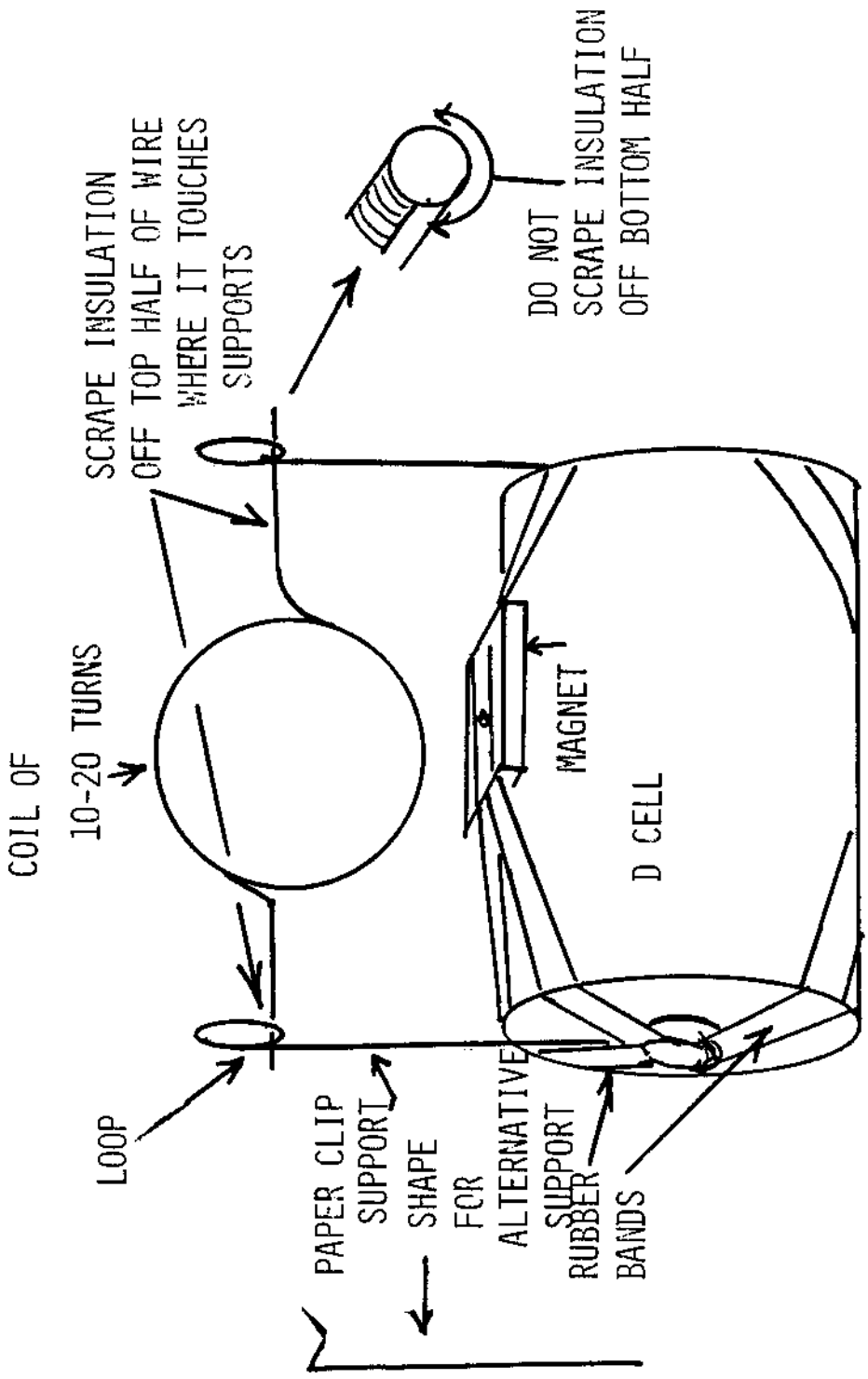
Experiment 12.11

The simplest electric motor

Materials: two rubber bands (large), small ceramic magnet, two paper clips wire supports, #22 enamelled coper wire, sand paper (or knife), a D (or C) battery.

Instructions: The diagram is almost self-explanatory. A coil of wire of ten or twenty turns is wound on a former - the D cell itself will do for this. The two supports (straightened paper clips will do) have loops at the ends - they can be formed round a pencil - one or two rubber bands hold these wires and the magnet on to the battery as shown, the wires making contact with the terminals, the magnet being on top. If preferred, a "v" shaped support, as shown in the figure may replace the loop. The ends of the coil must now be scraped, or sandpapered on one side only, with the angle to the coil as shown (coil vertical) so the torque on the coil is in one direction only. The device is put together and the coil set spinning. A number of further suggestions (from Scott Welby's article) are:
Does the motor have a preferred direction of rotation? Why?
Does reversing the battery or magnet reverse the direction? Why? How does the shape of the coil (armature) affect its operation?
What is the optimum number of turns of wire for best performance?
Put an ammeter in series with the coil to measure the current. Estimate power output.

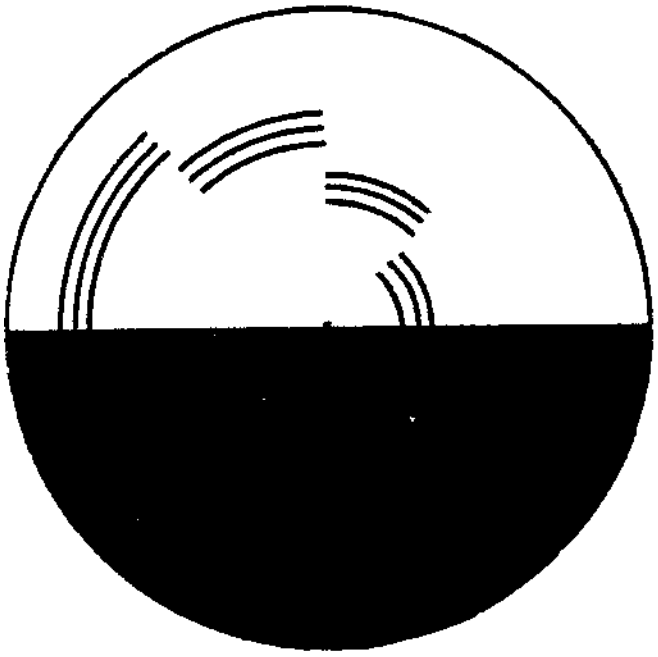
1. Physics Teacher 23, 172 (1985) (Scott Welby)
2. Physics Teacher 17, 308 (1985) (Rudy Keil)

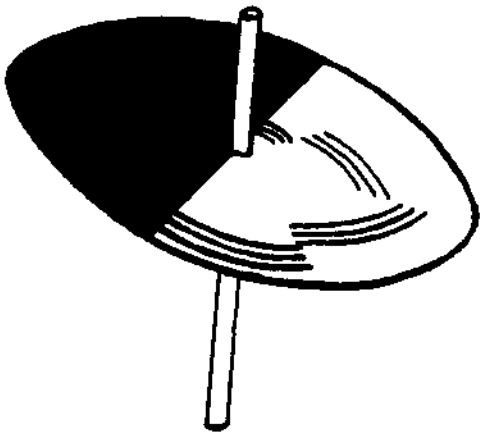

COIL OF
10-20 TURNS
SCRAPE INSULATION
OFF TOP HALF OF WIRE
WHERE IT TOUCHES
SUPPORTS
DO NOT
SCRAPE INSULATION
OFF BOTTOM HALF
MAGNET
D CELL
LOOP
PAPER CLIP
SUPPORT
SHAPE
FOR
ALTERNATIVE
SUPPORT
RUBBER
BANDS

Experiment 13.01 Benham's Top - an experiment in psychophysics.

Materials: straw

Procedure: Cut the disc below from the sheet, poke a small hole at the center using a pencil point, then push a piece of straw about two inches long through the hole. The disc can now be spun as a top.



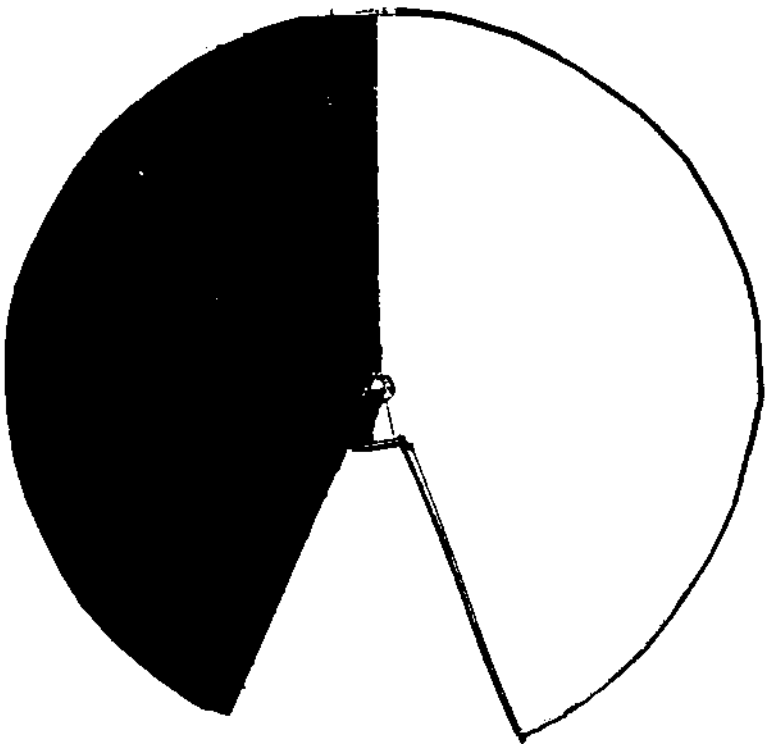


Spin the top clockwise, and note how the outer rings appear darkest, and the inner rings colored, even though they are black and white. Now, reverse the rotation of the top and note how this time it is the inner rings which appear dark, and the outer rings appear lighter and colored.

Qualitative: Why is this? Our eyes adapt to darkness in a variety of ways. After looking at a bright light for a short while, the nerves sending pulses to the brain become "tired" and cease to respond as well. On the other hand, the cells looking at the dark are "dark adapted" and give a much larger response to light. The cells which respond to different colors recover at different speeds, so a rapid change from black to white may allow one color sensor to give its full output, but not another. The effect is to tint the disk that color which gives its output most rapidly. Spinning the disk at different speeds can lead to different colors--very slow, and all the sensors give full value. Very fast, and only a random selection respond, leading to grey.

Although the general principle behind this experiment is understood, the details of the physiological process is not well known at all.

A similar illusion was invented by Bidwell (1897). When rotated clockwise at about six revolutions per second with the slot above a colored object, the object appears its complementary color.



Experiment 13.02 Physical Perception - Optical Illusions

Materials: Scissors, hot and cold water, cups

Procedure: The importance of sensual illusions lies not only in the amusement they provide. They are also important in helping to understand the mechanism of perception, and in teaching us we can't always believe our senses.

1) Illusions and Distortions Due to Fatigue or "Adaptation"

Among the most common sensual illusions are those which arise when we suffer from prolonged stimulation. Here are some ways of adapting the senses to give distortions.

1. Weight

After a heavy book is carried for several minutes at arms length, the arm feels light, and may involuntarily rise up several inches.

2. Temperature

Put one hand in a cup of hot water, the other in a cup of cold water. After a few minutes or so, put both hands in a cup of tepid water. Although both hands are now in water of the same temperature, the one that was in the hot water feels it as cold, while the other feels it as hot.

3. Taste

Sweet drinks taste gradually less sweet. Try keeping a sweet soda drink, such as a cola, in the mouth for a few seconds and then taste fresh water. It will now taste distinctly salty.

4. Loudness

After hearing a rock concert, the outside sounds quiet.

5. Velocity

Distortion of apparent speed is common while driving. A car moving at 30 mph seems to be moving almost ridiculously slowly after an hour's continuous driving on a super highway. Traveling by train, where the forward motion is smoother than by car, a common sensation of drifting backwards occurs when the train stops at a station. Cut out the diagram on the following page; push a pencil through the center and rotate it by rolling the pencil between the palms of the hands. Better still, spin the figure on a record player. If, on rotating, it appears to expand, on stopping, the whole figure seems to shrink.

6. Brightness

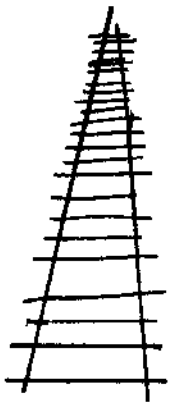
If you stare at a lamp for a few seconds, then look at a white wall or sheet of paper, the effect of adaptation to white and black will be seen quite dramatically. Adaptation to the bright light will produce a corresponding dark area on the wall or sheet. The brightness and colors of such after-images are pretty well understood. Fixation on the lamp reduces the

sensitivity of the retinal light receptors on which this area falls. On looking away, we see the region corresponding to the part of the retina which has lost sensitivity by being exposed to bright light as darker, simply because it transmits less signal to the brain. The frequency of nerve impulses from this region is reduced, just as when in fact we look at a darker region of an object. This adaptation also applies to colors. After looking at a green y-blue colored object, on looking at a white sheet we see the object, but in its complementary color red. The eye is adapted and no longer sensitive to green.

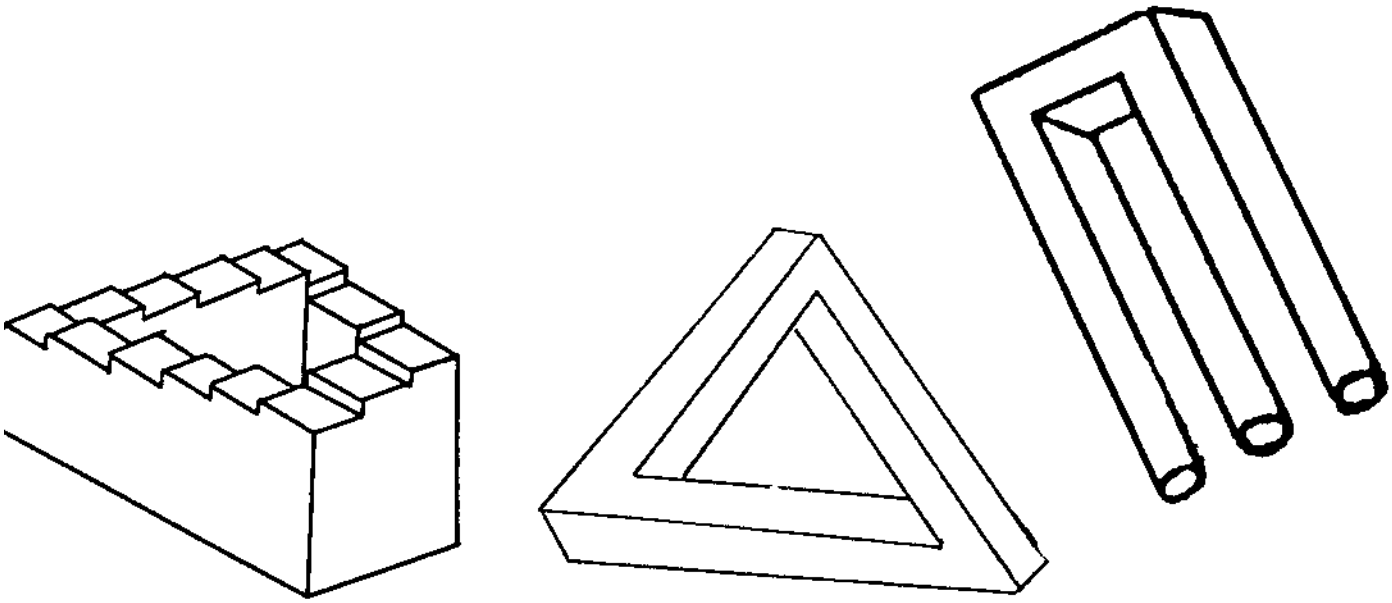
2) Optical Illusions

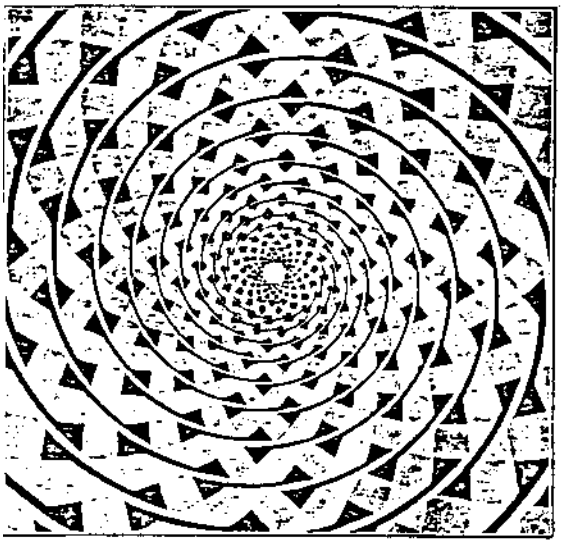
Optical illusions can be divided into two groups. One set is purely physiological. It depends upon the physical response of the eye to stimuli--a simple example of this is the vanishing of an object whose image lies on the blind spot. Look at the cross in the figure below with the left eye, and move the page back and forth. The dot will vanish at a point when its image falls on the blind spot of the retina. Correspondingly, the cross vanishes if you look at the dot with the right eye. Our brain fills in the absent visual response with its surroundings.

The second type of optical illusion is psychological, depending upon our association of ideas and visual patterns which we have developed over the years, and would, for example, be absent, in the case of a new born infant. Such illusions are those which arise from perspective -- two lines drawn to converge at a point, as shown in the figure below, look like railway tracks running away from us to infinity at the "vanishing point".

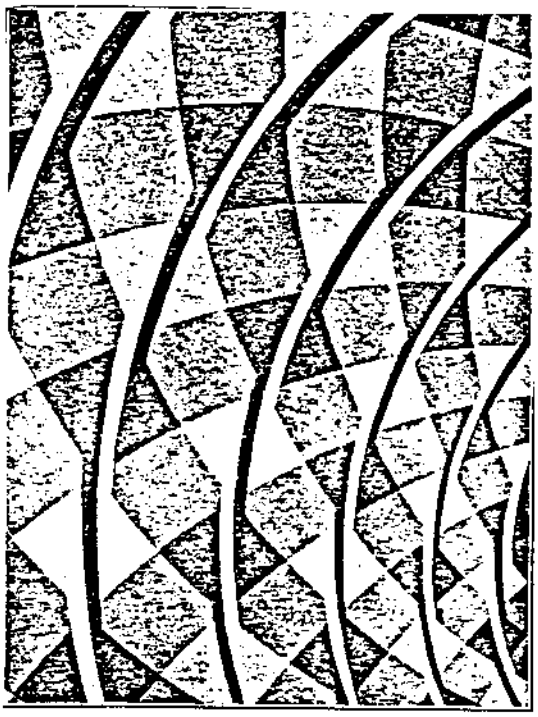


Often optical illusions are a combination of the psychological and physiological. For example, the television and motion picture industries are based on such illusions. Successive pictures in sequence of time are flashed on the screen at the rate of 16 to 25 per second, and because the physiological response of the eye is not sufficiently rapid to separate them, - the so-called "persistence of vision" - we see them as continuous motion and not as individual pictures. This effect is physiological - however the illusion of depth in the scene itself is psychological and based on our ideas of perspective mentioned above, which we have built up through looking at objects from different vantage points, and inferring their solid appearance from a knowledge of one view. Our mind puts in what the perspective does not provide. Interest in such perspective illusions has been recently revived by M. C. Escher, and several new perspective illusions have recently evolved - such as the perpetual staircase and the impossible prongs starting with two, and ending with three, and the triangle - each corner of which is a right angle, shown overpage. They depend upon the fact that the eye does not comprehend the whole of a picture at one time, but only sees and interprets a small portion.





Illusion in which concentric circles appear to make a spiral.



Enlargement of preceding figure, showing true nature of concentric circles.

In the nineteenth century, eminent scientists such as Zollner, Hering, Jastrow, Poggendorf and even Helmholtz suddenly evinced interest in explaining illusions. Nearly always, they failed to realize illusions are more than mere laboratory curiosities, being the outward expression of human perception and judgment. Interest vanished for a while until in the 1920s the field of transactional psychology was born. and men like Adelbert Ames devoted their lifetime to visual perception.

Illusions are most difficult to categorize in any logical way. R. L. Gregory's book, "The Intelligent Eye", provides the best insight.

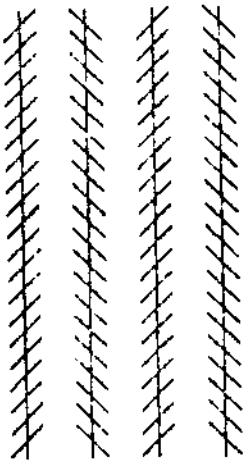
The earliest of the so-called "hatched line" illusions: is Zollner's paradox. (a) Although the long lines are parallel, the small cross hatching lines produce the very real illusion of making the vertical lines alternately diverge and converge - they do not appear parallel. Zollner discovered this on some dress material. Ward's illusion (b) is a variation of this, the parallel lines bowing in, and in Hering's illusion (c) the lines bow out.

In Poggendorf's illusion, (d) the visual question is whether the left hand line is a continuation of the upper or lower line on the right. All these illusions are based on the misleading effects of lines - the rest of the pattern other than the lines must be considered. The eye can only interpret relative effects - even a straight line is interpreted with respect to its surroundings. The illusions (e) have a similar basis - the eye being led inward by converging lines.

Oscillatory Figures

It is clear from the forgoing illusions that the brain interprets patterns of the eye in terms of external objects. A fundamental problem is how the eye splits the pattern into objects and surroundings. The figure-ground illusions of (f) Rubin's faces - vase is a case in point. Is this two faces (objects) looking at one another, or a vase? Boring's ambiguous "My wife - and my mother-in-law" is similar (g) The ear of the pretty girl becomes the eye of the mother-in-law.

Schröder's staircase illusion (h) is similar - are the stairs the right way up or upside down?



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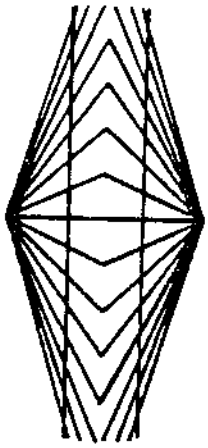

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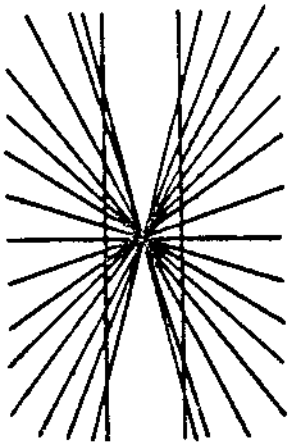

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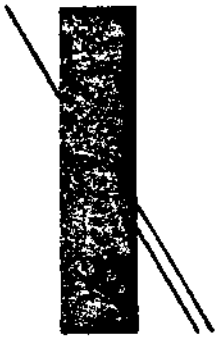

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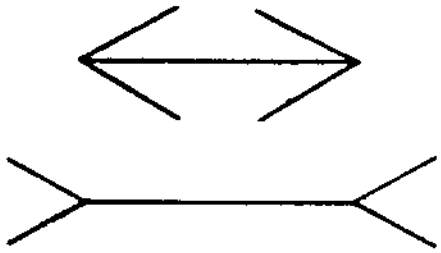

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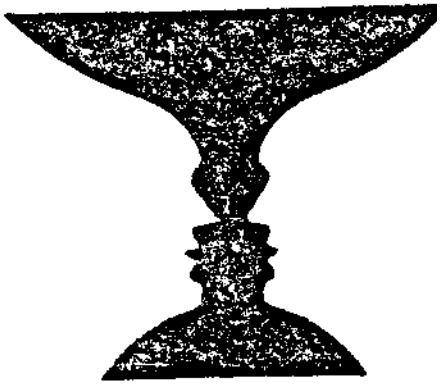

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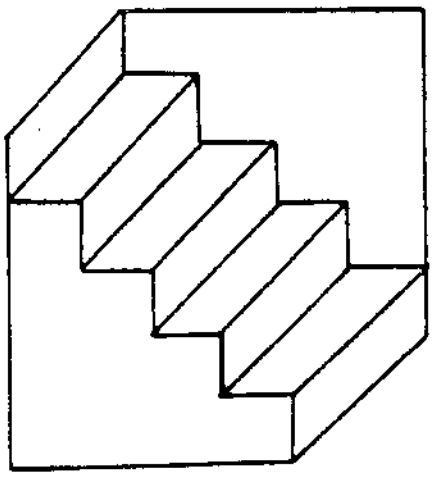
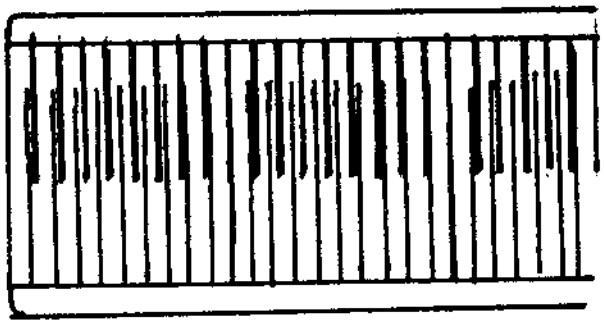


H

Experiment 13.03. Moiré Patterns

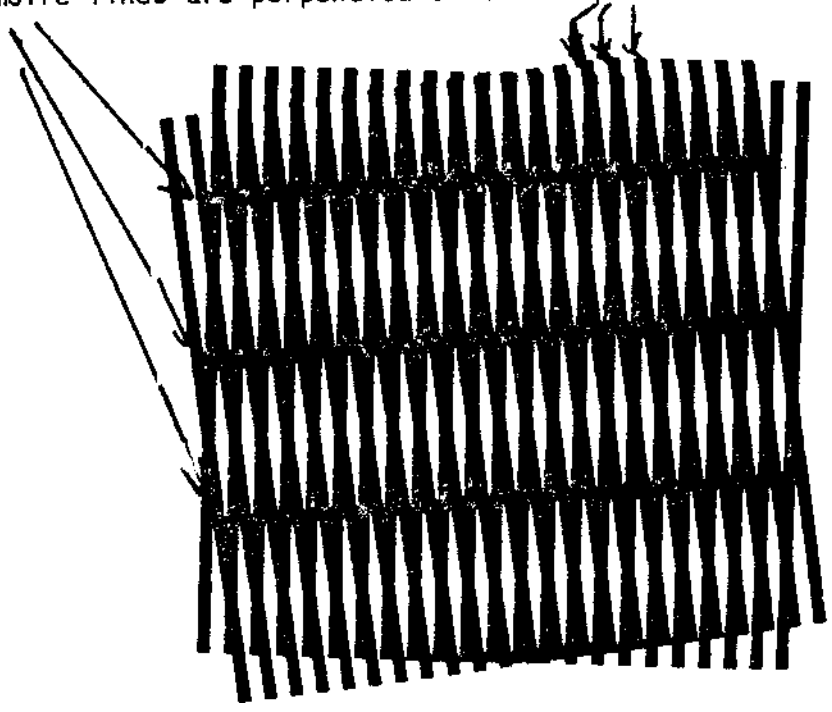
Materials: Scissors

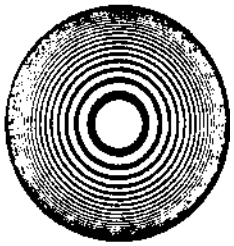
Procedure: Perhaps you have noticed that when window insect screens overlap, patterns are produced which change wildly with a slight movement relative to the screens. These patterns are called moiré (pronounced mwareh) patterns. Two sets of railings on a bridge, or two combs with different teeth spacings also produce such patterns. The distance in which the pattern repeats is large, if the difference in spacing between the teeth is small.

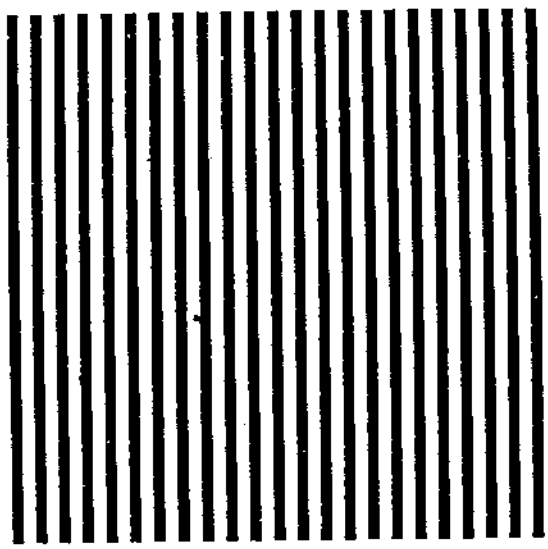


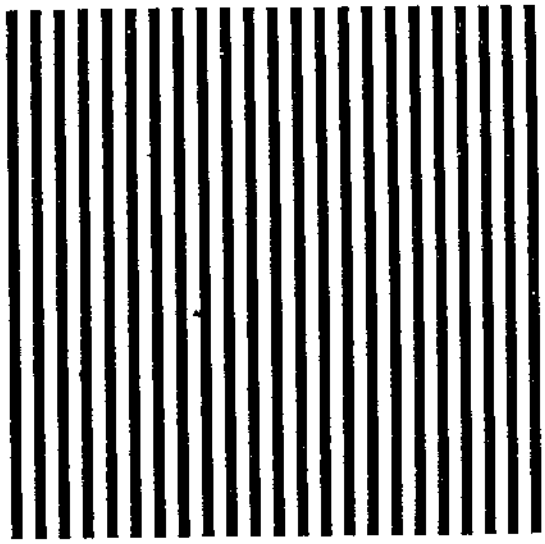
Some other patterns are shown below, and over page. Cut out two similar patterns, turn one over, and place it on top of the other pattern, so the two ink surfaces are in contact. Hold the two overlapping patterns to the light, so you can see through the two sheets of paper at the moiré pattern produced.

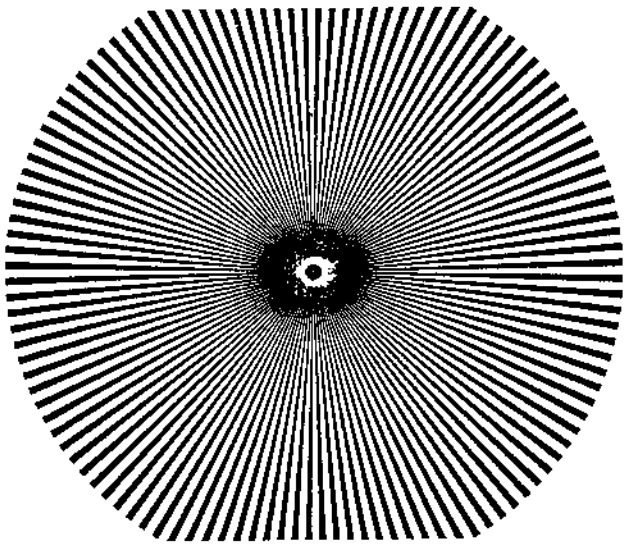
Move the patterns about on top of one another to see how they move. Describe the patterns produced. Examine the straight line patterns, and try to explain why the moiré lines are perpendicular to the pattern lines.

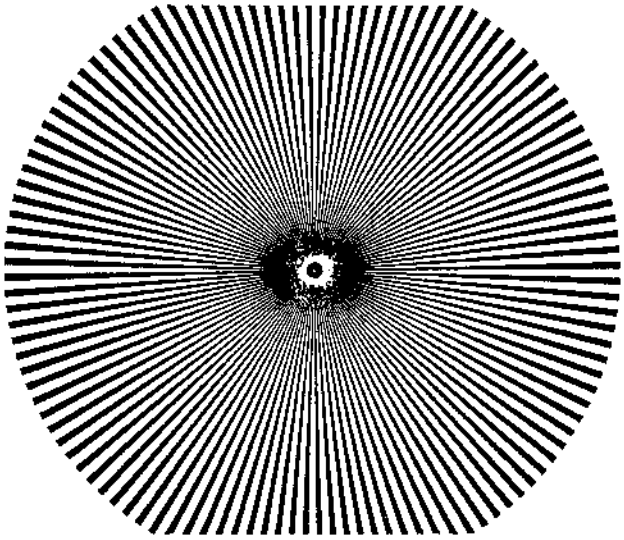


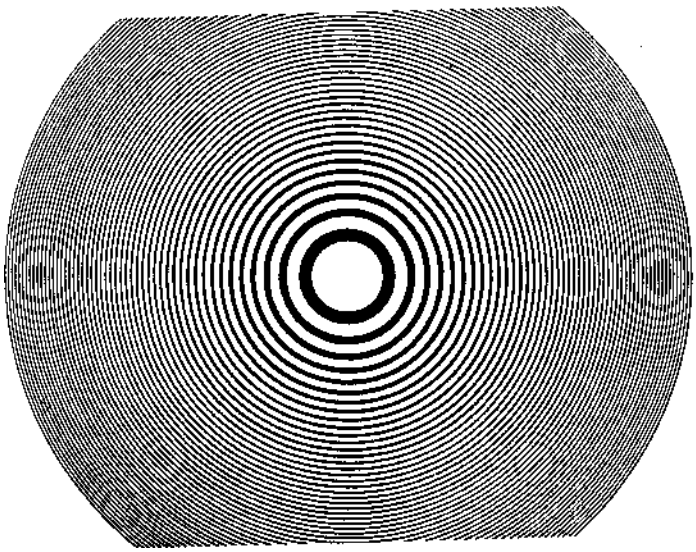


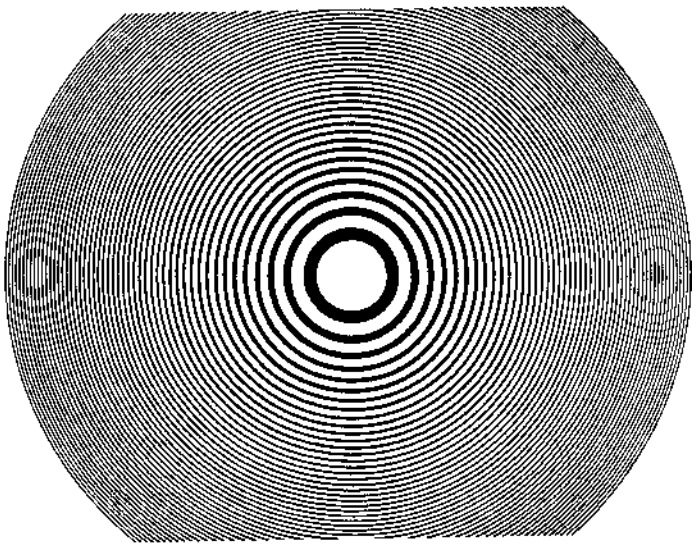












EXPERIMENT 13.04 Persistence of Vision

Materials: pencil, scissors

Procedure: Motion pictures and television depend on the fact that for a continuously flashing light, successive flashes become indistinguishable if the repetition rate is sufficiently rapid. So, the eye sees continuous action if a succession of pictures (each a little different from the last, because of the motion of the objects depicted) is placed rapidly before the eyes. The physical or physiological reason behind this is the time it takes the rod and cone sensors of the eye to recover. During this period the eye cannot perceive a complete new picture.

The earliest efforts at representing motion in this way occurred in the early and mid nineteenth century, and you will construct a typical device, called a "phenakistoscope". (All such devices had high-flown pseudo-Greek names, ending in "scope".) Cut out the black disk, and carefully cut the slots marked. Now, cut out the other disk. Take a new (so that it is long enough) sharpened pencil and push the point through the center of the black disk, continuing to push it until just before the other end. Now push the point through the disk with the girl on it. You are now ready to make the device work. Hold the pencil between the fingers and palms of your hands, as shown, and put them together, so the pencil rotates rapidly, peeking at the pictures through the slots simultaneously. You should see the girl skipping. After reading the instructions and questions, cut out the disk overprinted on this page. This shows an electron going round the nucleus in an atom. It gives out a photon of light, dropping to a lower orbit, and the photon travels to the next atom where it is absorbed.

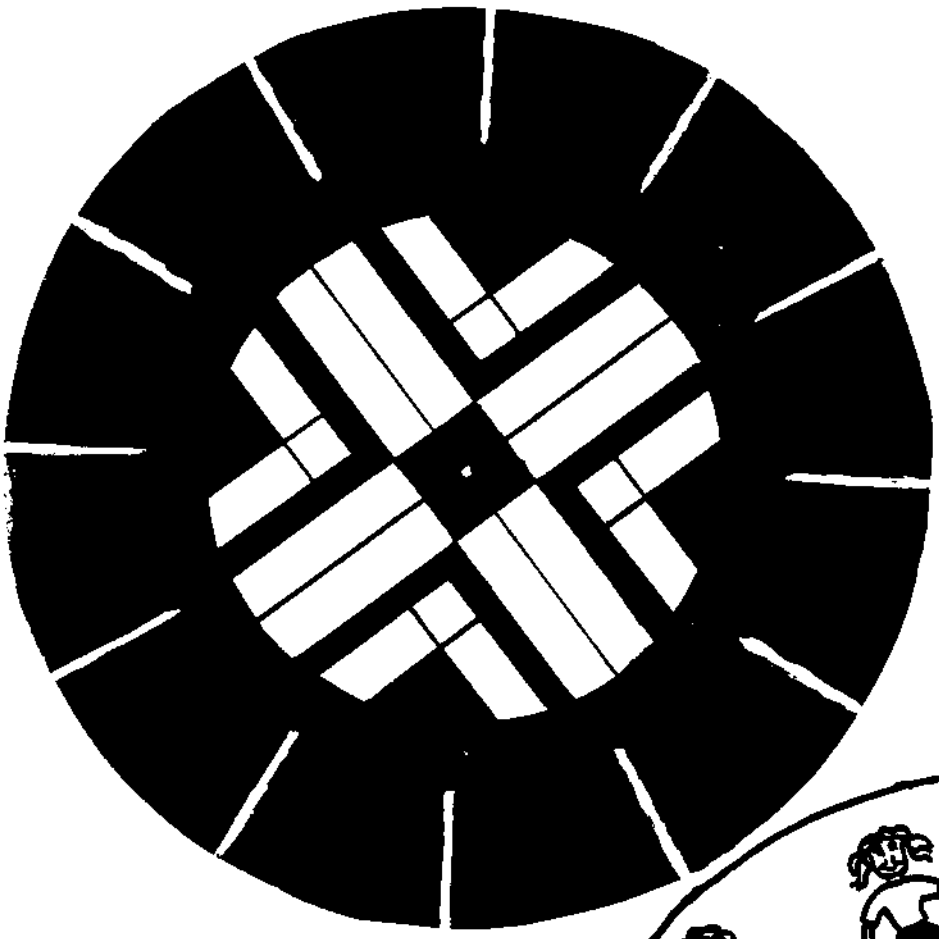
Try to answer the following questions.

1) Estimate how many frames (pictures) a second are required to avoid jerky motion, such as you see in old-time silent movies, which have too few frames per second. As you rotate the disk, get a friend to count "one, two, three" for each rotation, from a mark on the edge of the disk. Now, a second friend can look at a clock, and see how long the "one, two, three" took. To give some idea, silent movies run at sixteen, sound movies at twenty four, and television thirty complete frames per second.

2) Reverse the slotted disc so that the white side faces outward. Does the device still work? Why ?

3) The slots in the disk are very narrow, so that you only see the picture about a tenth of the time--the rest is dark. In movies, the time the screen is illuminated is much longer than this--at least half the time. Enlarge the slots to find out why it is necessary that they be so narrow in the phenakistoscope. Why is this?

4) Why does the writing on the disk shown on this page not affect the picture you see?



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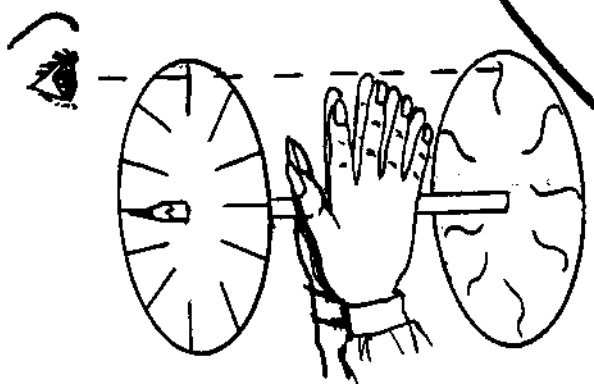
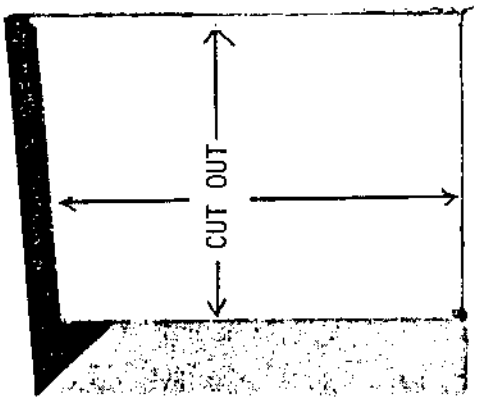
POINT
HERE

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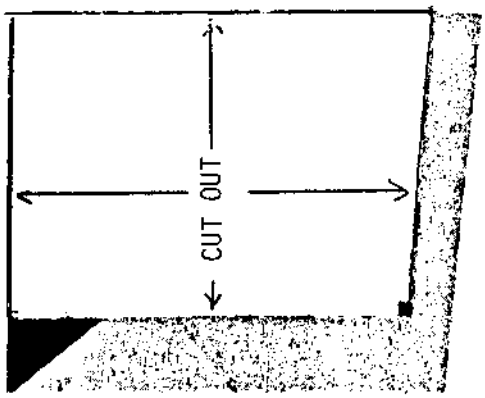
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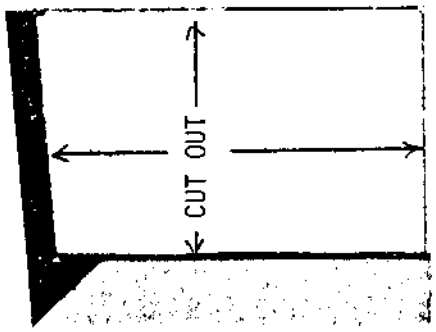
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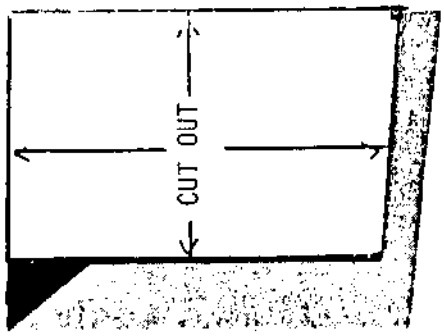
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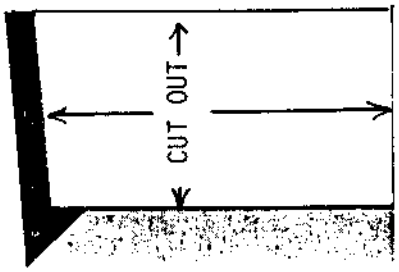
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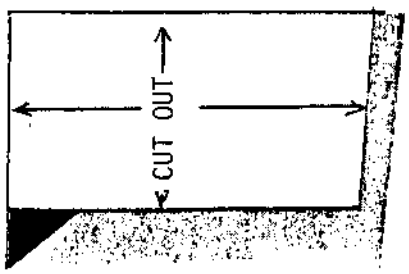
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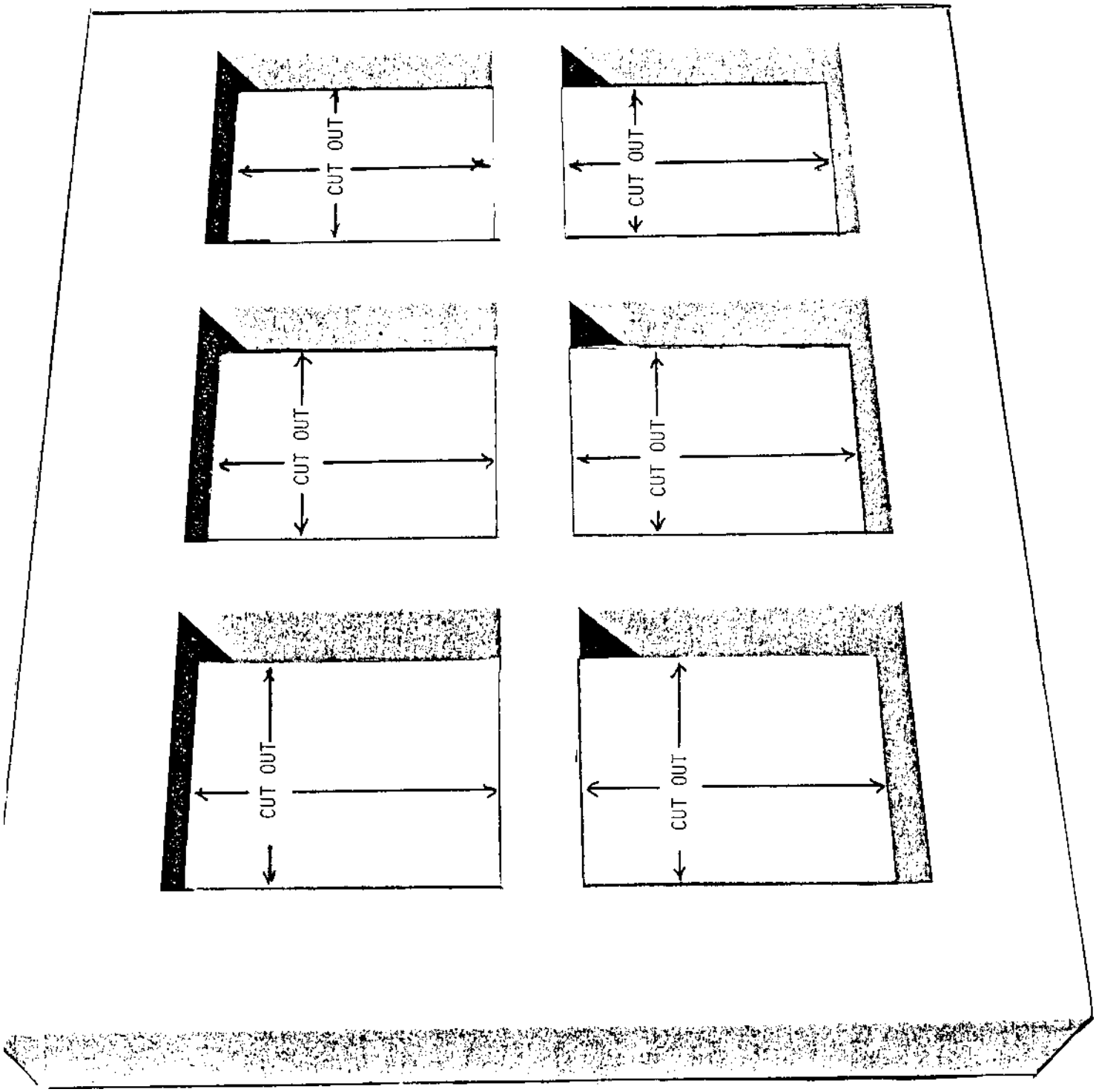
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Section 14

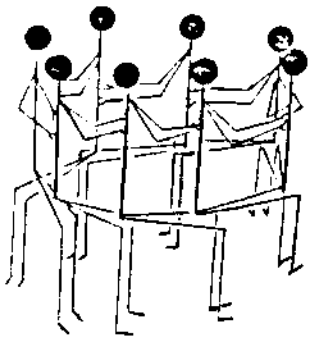
Introduction

There has been a move afoot among child psychologists for quite awhile to change some of our attitudes toward games. In the past, games have been primarily competitive, the object being to beat the opponents. Any cooperative spirit arose through one team combining against the other. Not all children are so combatively inclined, however. As a result, games have been devised which allow for a spirit of cooperation without the concomitant agression. One such is the lap game, (p. 172 of the New Games Book). In this, the group forms a circle, and each individual sits on the lap of the individual behind. The world record used to be 1,500 lapsitters. Of course, if one person falls over, a cooperative effect--essentially a soliton wave of non-lap-sitters--moves around the circle. The speed with which this occurs, though not equal to the speed of sound, is nevertheless very rapid. The thought occurs that many such games could be devised to demonstrate physical principles. This was brought home by Ruth Howes and James Watson, of Ball State University, demonstrating physical principles using the students themselves. The point was made that, in a large class, interaction on a personal basis, not merely between the professor and the student, but also between the students themselves, is virtually non-existent. Furthermore, such large classes are given, more often than not, in vast auditoria not designed for physics use, where there are no apparatus storage facilities, and it is difficult for the students at the back to see. At Ball State, they invite the students down, and a few of them mill around, bumping into one another, pretending they are "gas atoms". This contact sport is evidently much appreciated by the students, provided it is not carried too far. Then more students come down, making closer contact, hands on shoulders, but breaking away to put hands on the shoulders of different students to form a liquid. Then, they put hands on the shoulders of the nearest individual and stick--a solid. Ruth Howes mentioned several other such simulations, which serve to

1. wake up the students
2. act as demonstration experiments
3. require no setting up time or equipment

Acting out really drives home the point.

I hear and I forget.
I see and I remember.
I do and I understand.
Chinese Proverb

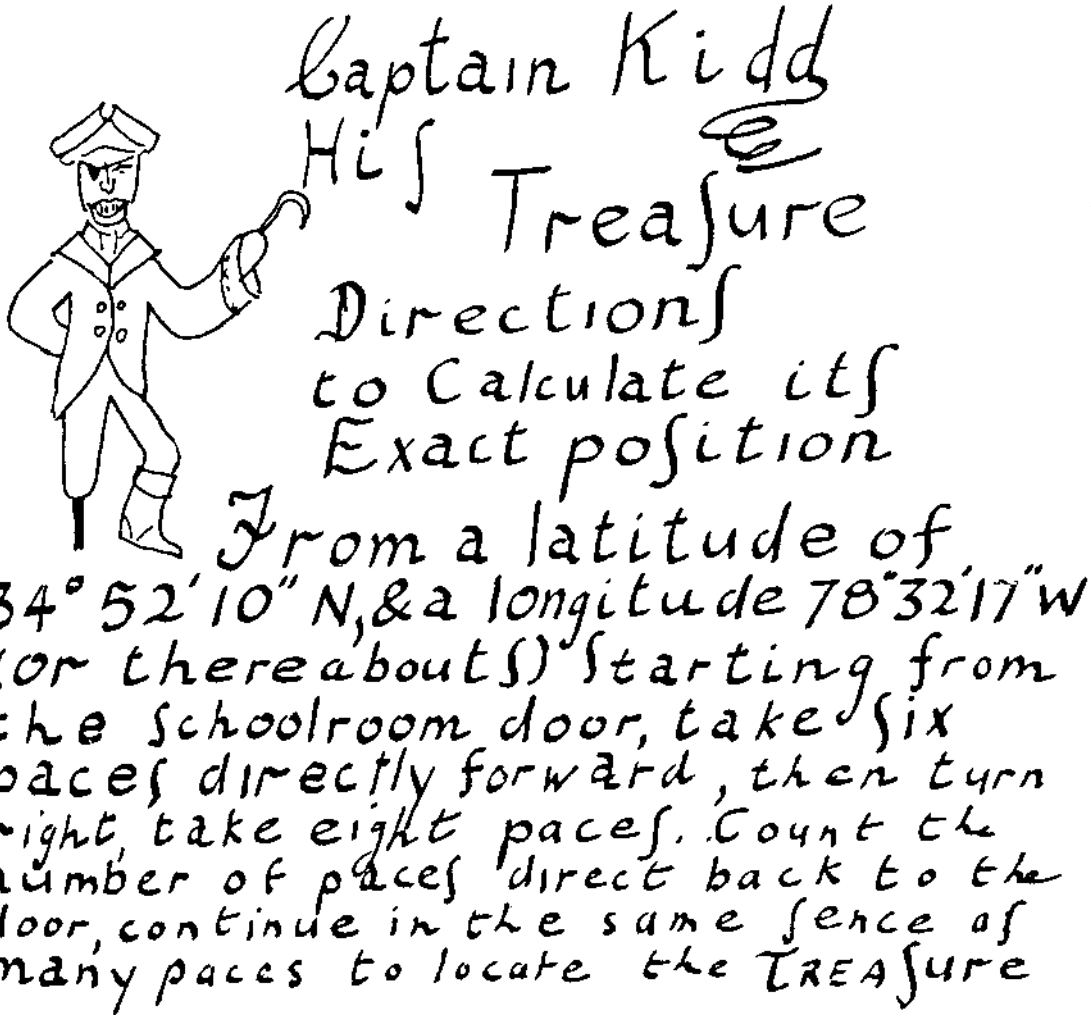


THE LAP GAME

Of course, the question arises as to how much is physics and how much game, but it seems an excellent idea in moderation. Which type of physics lends itself to such methods? People are particles, so clearly, gas kinetic theory is suitable--and in fact, many quantum phenomena can be described (short of tunneling through a potential wall.) I would like to give here some of the ideas we have tried out, together with the principle which it aims to demonstrate. Several books are a help in this field, such as The New Games Book, by A Fluegelman, published by Doubleday (1976); The Cooperative Sports and Games Book by T. Orlick, published by Pantheon (1978); and Learning through Movement, by P. H. Werner and E. C. Burton, published by Mosby (1979).

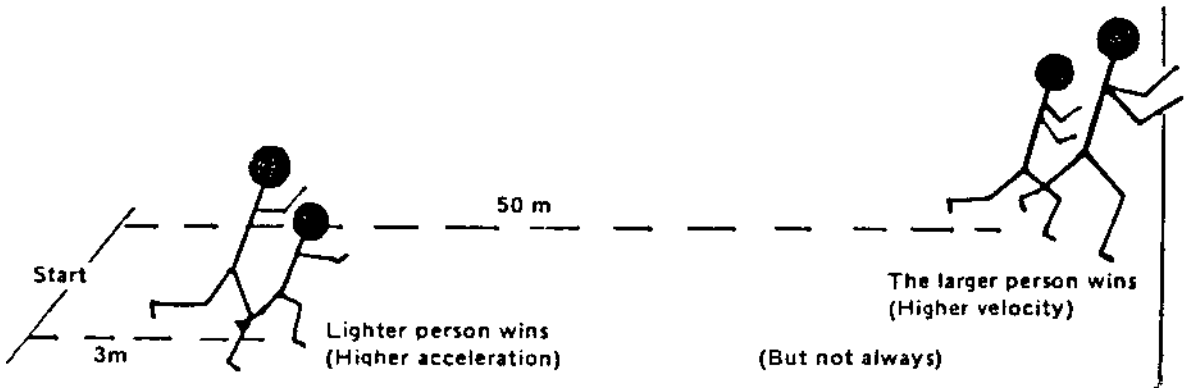
Experiment 14.01 Pirates Treasure Game (Vectors)

It is notorious that pirates always bury their treasure beneath some beach on a desert island, and then provide a nearly incomprehensible map to find it. The object of this game is to provide a suitable vector description for finding the treasure, using paces as the unit of length. It should be remembered that the pace was the unit employed by the Romans, whose professional pacers' sole job was walking between towns to measure the distance. So we can start by saying "take three paces north (or toward the blackboard, or whatever), and four paces west. Count the paces directly back to where you started, and continue beyond the same number,"--until you arrive at the desk with the treasure in it. The aim is to combine distances vectorially, to get where you are going to. One can extend this to three dimensions by going upstairs.


Captain Kidd
His Treasure
Directions
to Calculate its
Exact position
From a latitude of
34° 52' 10" N, & a longitude 78° 32' 17" W
(or thereabouts) Starting from
the schoolroom door, take six
paces directly forward, then turn
right, take eight paces. Count the
number of paces direct back to the
door, continue in the same sence as
many paces to locate the TREASURE

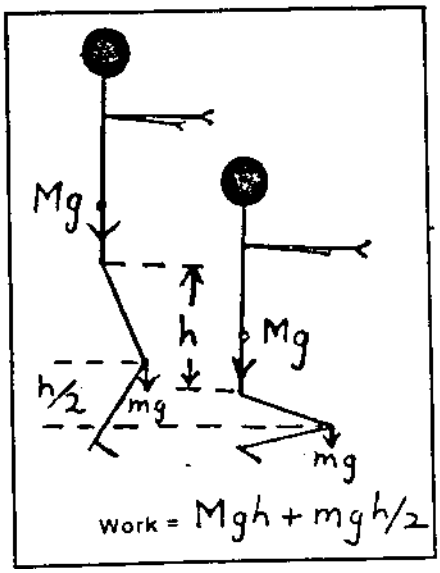
Experiment 14.02 The Three-meter Dash (Kinematics)

To emphasize the difference between velocity and acceleration, we have two races--one a dash of three meters (ten feet), and the other a more normal length up to 50 meters, or whatever is available. The students who accelerate fast are not necessarily the ones who can do well over distance.



Experiment 14.03 The Knee-bend Game (Energy and Power)

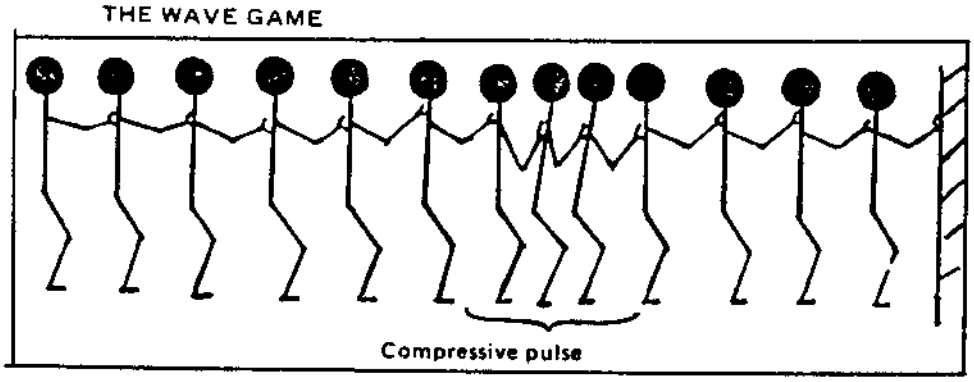
This is due to Dr. J. Johnson. The participants do a knee bend, and the distance from some suitable part of their anatomy to the floor is measured. They then stand up, and the same measurement is made from this position. Most people know their weight, so the work done, mgh, mass times the acceleration due to gravity times vertical distance risen, is easily calculated. For example, if your mass is 50 kgm (110 lb) and the distance risen on standing is 60 cm, the work is 50 x 9.81 x .6 = 294 Joules. The work performed on rising is not regained on sitting--unlike a bicycle running downhill, we do not store the potential energy on doing a knee bend--it is lost as heat. Some student is bound to have a watch with a second hand, so the next portion of the game is to see how quickly you can do ten, twenty, fifty knee bends. The power is then the rate of doing work. If you do 40 per minute, in the above example, the power would be 294 x 40/60 = 196 Watts. (Joules per second). Generally, the rate of doing knee bends is about the same for men or women, but women weighing less, their power is also correspondingly less. One can also perform a similar game running up and down stairs and measuring the power required--however, one should avoid giving older students heart attacks.



Experiment 14.04 The Wave Game

This one is great fun. Students stand in a line, fairly close to one another, and put their hands on the shoulders of the individual in front. The one in the front of the line rests his hands against a convenient wall. The last in the line gives a hearty push to the one in front, who (to avoid falling) pushes the one in front, and so on. When the front is reached, a push is given against the wall, and the compressive wave travels toward the back. About the only problem in this game is attenuation of the waves--a really good push is needed to avoid this. To simulate reflection at an open end, the last person in line pulls the shoulders of the individual in front, who pulls the shoulders of the next in front, and so on. The front of the line, on being pulled back, and having no one to tug on, falls back and "reflects" the rarefaction as a compression. This is not as self-generating as the first part. The wave will rapidly attenuate unless positive feedback is inserted--each student, on being pulled back, must make a conscious effort to pull back the student ahead. I have found, when the students see what is going on, that it makes understanding a difficult concept much easier--and enjoyable!

Transverse waves can be simulated by the last student pushing the one ahead sideways. Again, this travels to the front, where, if the student has nothing to hang on to, a reflection of the same sign occurs. If the student hangs on to a doorway, or other solid object, the pulse is reflected with change of sign.



If you don't want the students to stand up, they can perform a similar experiment in their seats. Each student grabs the nearest hand of the student on either side, so that a chain is formed. On command, the end student squeezes the hand of the adjacent student who, feeling the squeeze, squeezes their nearest neighbor - and so on until the last student, feeling the squeeze, yells or puts his hand up. The time for this, divided by the number of students, is the reaction time. A transverse wave may be generated by raising and lowering the neighbour's hand, instead of squeezing. The neighbour in turn raises and lowers his other hand and that of his other neighbour. Watching this up-down move round the room is fascinating. One can, of course, generate a standing wave by reflection at both ends.

14.05 The Kinetic Theory Game

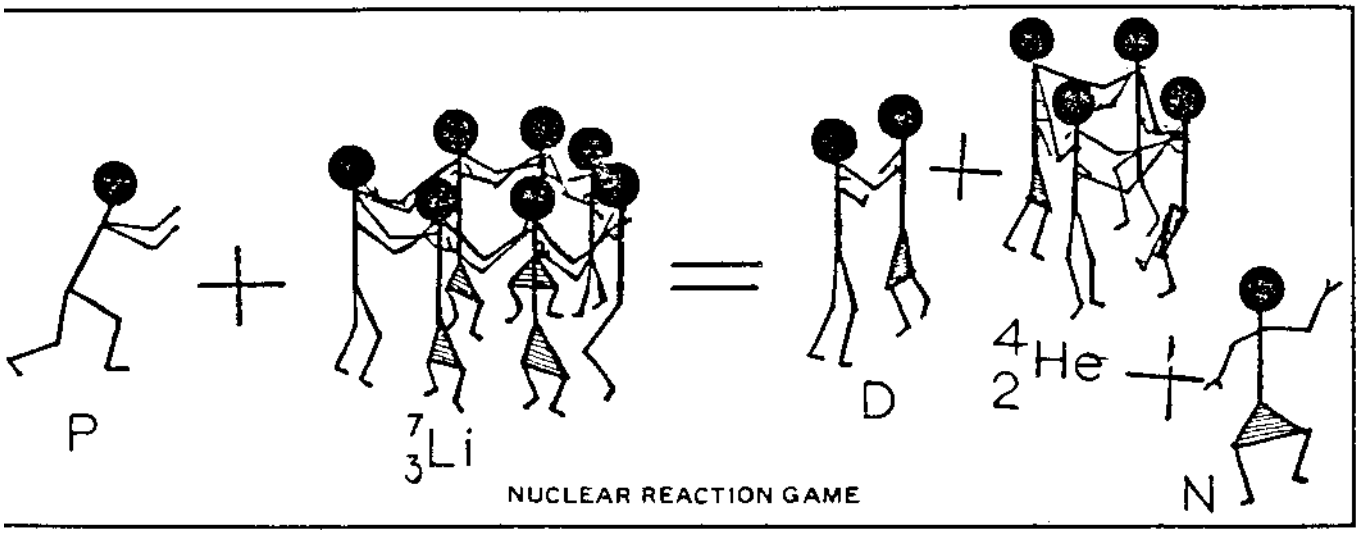
Since people are particles, the motion of particles represents a good opportunity for games. The aim is to demonstrate the three states of matter--solid liquid and gas--and the effects of pressure, volume and temperature. The demonstration of a gas involves a few students dashing madly about, bumping into one another, and the walls of the room. The faster they run, the more momentum delivered to the walls--the "pressure" is proportional to the "temperature". The smaller the space in which they can operate, the more often they strike the walls--the "volume" is inversely proportional to the "pressure".

Now, as more students are added to the gas, it "condenses" -- the students are effectively jostling about in a crowd. There is no "mean free path" as before, but motion still occurs . If, now, they attach to one another--hands or shoulders or otherwise--they form a "solid"--their long range order remains the same--the relationship of one to another remains fixed.

14.06 The Nuclear Reaction Game

Since nuclei contain more neutrons than protons, the sex in the majority in the class are neutrons. Elastic scattering--a neutron runs in and bounces off an alpha particle (two girls and two boys hugging hands around shoulders). The bouncing should be done using the hands only to prevent accidents.

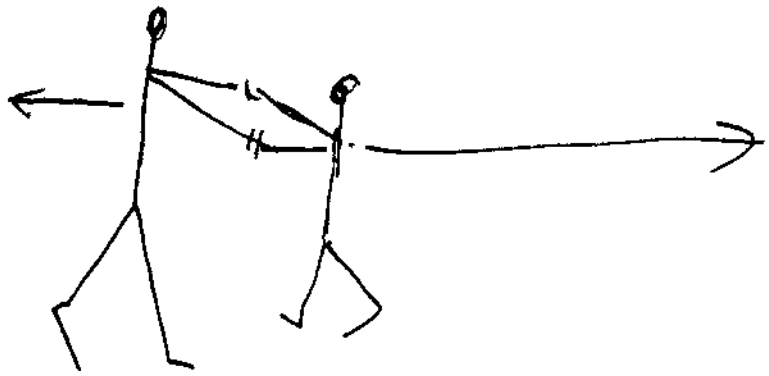
Nuclear reaction--we can have a knockout reaction, where one child is knocked out of the "nucleus" of five or ten--or a pickup reaction, when one child is pulled off the group--or a high q reaction--children in the nucleus are hand to hand so they can rapidly push away from one another when triggered by an incoming "particle"--or a fission reaction--the "nucleus" splits into two with release of a neutron. One can let the nucleus be split on a random basis, and see what comes out. Is the product stable? Is the reaction exothermic (the students deliberately push one another away) or endothermic (only the impact of the foreign nucleon provides the energy to breakup the nucleus). The multiplication which occurs when a reaction or bomb goes supercritical can be simulated by having groups of five (or more) students form a nucleus. When one "neutron" bumps into them, the nucleus fissions into two groups of two (or more) plus a neutron, which goes on to fission another nucleus. A class of thirty can provide six "nuclei", somewhat small for a reactor, but it does drive home the principle.



NUCLEAR REACTION GAME

14.07 The collision game

Basically two students place hands to hands, in the "pat-a-cake" position, and push one another away. Who moves fastest and farthest? Then, they rush toward one another and push away, in a similar "collision" process. See the effect of mass, with a small and large student -- and velocity.



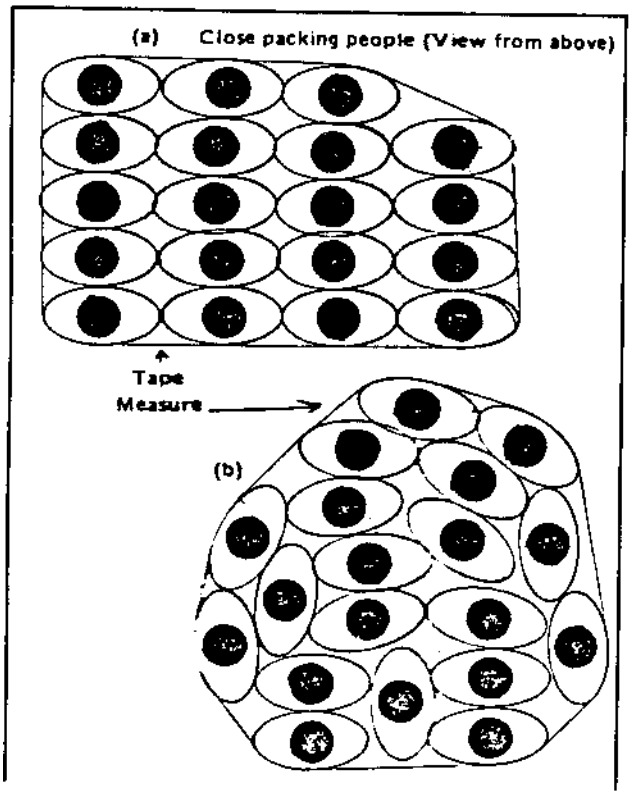
14.08 The electron- in-a-wire game.

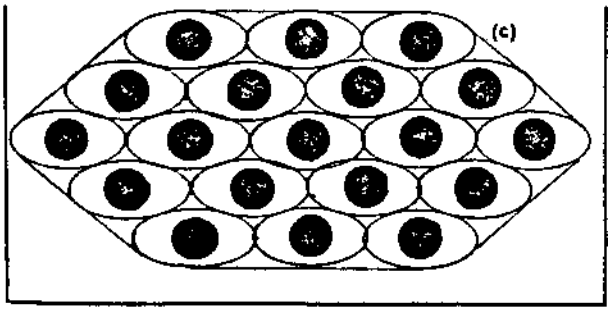
When we put a voltage on a wire, why don't the electrons run out the end? For this game, a small student represents the electron, to move from one side of the room to the other. Students stand, fairly close together, randomly, forming the atoms of the wire. The electron cannot move directly from one side of the room to the other, but must bump into several "atoms" in the process, coming to rest, and starting off again.

14.09. The close packing game.

This is a dilly for people who like togetherness. How close together can a group of people get in a crowd? A useful aquisite is a tape measure, or piece of string, to be placed round the outside of the group. Different groups pack differently. For example, if you have large and small students, they should alternate, like atoms in sodium chloride. If they are all the same size, and very round, they pack hexagonally as do metals. This two-dimensional close packing is the same as one layer of either face centered cubic or hexagonal close packing in three dimensions. Raising hands makes the students rounder, and gives tighter packing. Hands down, we are smaller front to back than side to side and pack most closely as shown in figure (C) in a layered structure.

It seems the change in perimeter for people-shaped objects packed differently is much less than for circular objects. (a) in the figure has the largest perimeter, but (b) and (c), the random and close packed arrangements are very little different--only an inch or two. Nevertheless, it does prove easier to explain the concept of close packing in solids after the experience.





14.10 Lifting the body - Force

One student lies prone on the ground. The others gather round, and lift him (or her) by putting one hand under the body to lift up. If enough students are around, then one finger from each is enough. Divide the weight by the number of students lifting. The student can then be raised head high, and passed from hand to hand along the two supporting rows of students.

14.11 Reaction Kinematics

Have you ever had a problem trying to explain statistical equilibrium in a thermo class? Try Vampire, a game from Transylvania, of course (New Games p. 123). Students close their eyes and mill around. The vampire keeps her eyes closed, but when she bumps into someone else, there is a difference. She snatches him and lets out a blood curdling scream. The victim becomes a vampire as well, on the prowl for new victims. Now for the physics (not in the reference), let us suppose there are N students, who each collide, on an average, every τ seconds. There are N/τ collisions per second. If we have n vampires, the probability of a collision between a vampire and a non-vampire is $(N-n)/(N-1)$ (we subtract the 1 for the vampire doing the colliding). So the rate of vampire production is (number of vampire collisions/sec)(probability of a collision with a non-vampire)

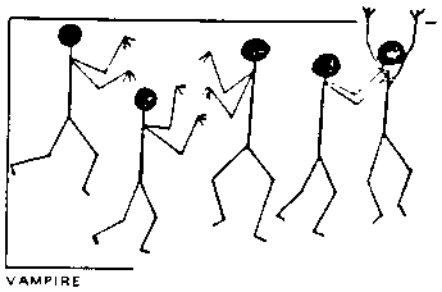
$$= (n/\tau)\ (N-n)\ /\ (N-1) = dn/dt$$

where t is the time

This means the rate of vampire production increases very rapidly as time goes on--exponentially in fact, since, if N is large $(N-n)\ /\ (N-1) \simeq 1$ at first, and so $dn/dt = n/\tau$, and $dn/n = dt/\tau$ Integrating, $\log n = t/\tau$ + constant, and $n \propto \exp(t/\tau)$ This is a dramatic effect. Every few seconds the referee stops the game and counts the vampires. Plotting vampires versus time gives a marked exponential increase.

This exponential growth is very typical of a number of different chain reactions--the best known being that occuring in a nuclear reactor, where the reaction grows exponentially once criticality is reached.

As n approaches N, $n\ /\ (N-1) \simeq 1$ so $(N - n)\ /\ \tau = dn/dt$



2

$$dn/(N - n) = dt/\tau$$

$$\log (N - n) = - t/\tau + \text{constant}$$

$$(N - n) \propto \exp. (- t/\tau)$$

So, towards the end, n approaches N more and more slowly, because fewer and fewer non-vampires are left. Nevertheless, ultimately everyone becomes a vampire and the game would end.

To avoid this we insert the additional condition that when two vampires feast on each other, they transform back to normal mortals. Now, our rate of vampire production has a negative term proportional to the number of vampire-vampire collisions,

(number of vampire collisions) x (probability of a vampire collision with a vampire)

so

$$\frac{dn}{dt} = \frac{n}{\tau} \times \frac{(N-n)}{(N-1)} - \frac{n}{\tau} \frac{(n-1)}{(N-1)}$$

We shall get statistical equilibrium when the rate of vampire production = rate of non-vampire production, i.e. when $dn/dt = 0$ which will occur when

$$(N-n) = (n - 1) \quad \text{or} \quad N + 1 = 2n$$

i.e. almost half the students will be vampires.

See how long this takes, and, by counting vampires again, how accurately the statistical equilibrium is maintained. Chemical reactions, of course, are of this nature, where, when two molecules collide they may react to give a product, but when the product molecules collide, they can reverse the process and give the original constituents. The rates of reaction are proportional to the product of the density of the two constituents reacting, as in our game. The nice feature of the game is that statistical equilibrium comes at about 50%, so it is easy to picture what is going on.

A living experiment in statics (p 57 New Games Book), Four stout hearted hulks on hands and knees form the bottom layer; three mid sized inner directed individuals climb on their backs to form the next level, and two small courageous acrobats above them. Top it off with one light, expendable child. This two dimensional force pyramid is shown in the figure 2, to demonstrate the distribution of weight. Knowing the mass of the people involved one can easily calculate the forces. With a large group, a round base, like a rugby scrum can be used, with succeedingly higher levels--a Spanish specialty which can reach great heights (calculate the forces--several hundred pounds)

From the Figure:

$F_1 = m_1\ g/2$

$F_2 = (F_1 + m_2\ g)/2 = (m_1/2 + m_2)\ g/2$

$F_3 = (m_1/2 + m_3)\ g/2$

$F_4 = (F_2 + m_4 g)/2 = ((m_1/2 + m_2)/2 + m_4)\ g/2$

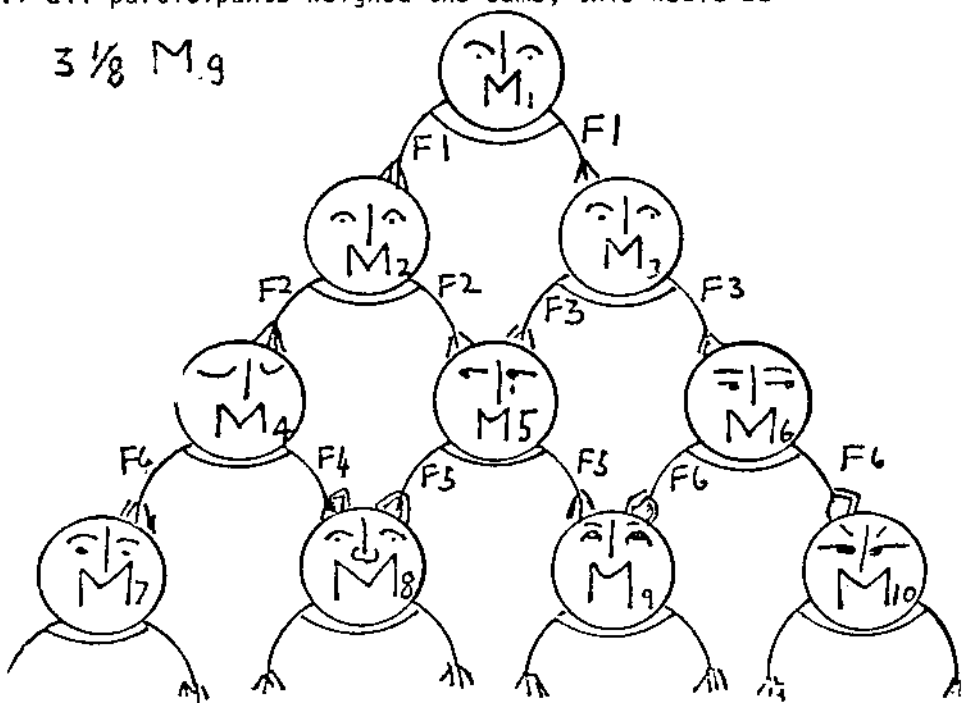
$F_5 = (F_2 + F_3 + m_5 g)/2 = ((m_1/2+m_2)/2 + (m_1/2 + m_3)/2 + m_5)\ g/2$

The weight carried by the eighth participant is

$F_4 + F_5 + m_8 g = (3\ m_1/8 + m_2/2 + m_4/\ 2 + m_5/2 + m_3/4 + m_8)g$

so, if all participants weighed the same, this would be

$3\frac{1}{8}\ M_8 g$



EXPERIMENTS INVOLVING MINIMUM EQUIPMENT

So far we have been looking at games involving no equipment and many students. Let us extend this to minimal equipment and two or more students. This would help involve and interest those students who believe physics is a dull subject. It is true, there is much hard labor in a study of physics--but too often students are put off before they really get started because the concepts involved are unfamiliar. If they can familiarize themselves with these concepts, then they are more likely to take the trouble to understand the mathematics and principles involved.

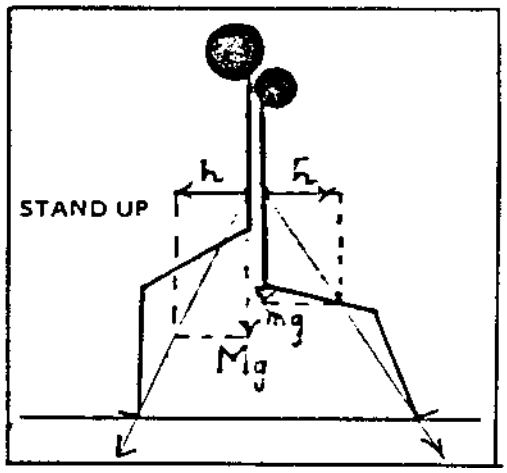
An important objection to games of this nature is that their content is low for the time spent; on the other hand, however, the impact on the student is high. It is quite surprising how much more firmly the concepts stick in the mind when associated with a pleasurable experience. Games such as these exemplify physics as an attitude, or a way of looking at things--an analytical approach--rather than a bunch of equations which must be memorized. Too often, we forget we look at life through different eyes from non physicists. We picture an ocean wave in terms of the motion of the water particles, the energy transfer--hydrodynamics. A "normal" person sees only the aesthetic side of it

Several such games are given in the "New Games Book" mentioned earlier. These appeal to a wide variety of age groups, and since their motto is "play hard, Play fair, nobody hurt", they will probably also be found suitable by the teacher.

Schmerlz (a rubber ball at the toe of a cotton tube sock), a toss and catch game, is the ideal demonstration for central forces. After whirling it round your head, you let go--and of course, it flies off tangentially to be caught by your partner. A fascinating game--but also a lesson in central motion and trajectories, if you think about them.

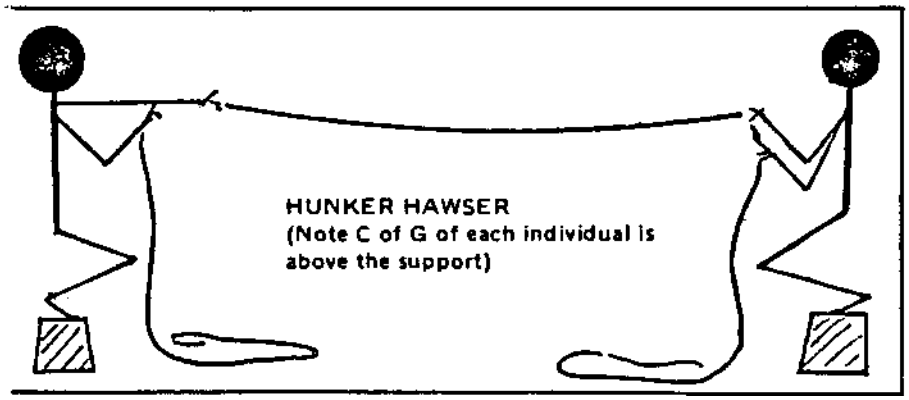
14.13 STAND UP

Stand-Up is a good game for two (or more) to show the principles of resolving forces. Sit on the ground back to back with your partner, knees bent and elbows linked. Now simply stand up together. You get a good intuitive feel for what is going on force wise. In addition to the vertical force you normally use to stand, participants exert equal and opposite horizontal forces on one another. Hence, the forces through the legs are as shown in the figure. Although more force is required than normal, it is in a direction which helps the pair to stand. When more than two participate, the force problem becomes a little more difficult, nevertheless, the forces between participants are basically horizontal. (p 65 New Games Book)



14.14 HUNKER HAWSER

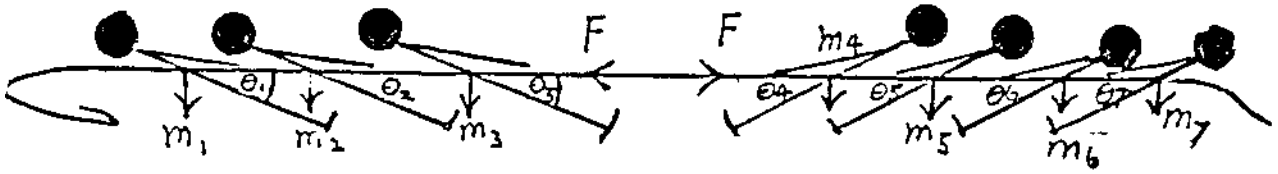
Hunker Hawser, another game for two , is a very practical demonstration of Newton's third law. The players hunker down on pedestals, which can be a block of wood, an inverted trash can or flower pot, set six feet apart, each holding on to the end of a rope about one inch in diameter and at least fifteen feet long. The excess rope lies coiled between them. At the starting signal players reel in. The object is to unbalance your oponent by tightening or slackening the rope. This is not as simple as it sounds, because if you give a good tug, your opponent may just let the rope slide, and over you go. However, it is clear that an impulse on the rope is transmitted to your opponent if he doesn't let go, and an equal and opposite impulse acts upon you. Instead of an impulse, a steady force can be applied if both lean back--but this is even more dangerous. In any case, the two factors--equal and opposite--are really brought home with a vengeance in this game.



14 CONCLUSION

INTRODUCING PHYSICS TO THE YOUNGEST STUDENTS

Particular attention to games should be given for younger students. Older students find physics difficult because the concepts are novel and unfamiliar. It is well known that, unlike languages or history, the first physics course is the most difficult. For this reason, the younger a student is when he is introduced to physics, the better. An excellent example of the way in which this can be done is given in Peter Werner and Elsie Burton's book, "Learning through movement"[3]. This is geared to primary grade children, and in chapter eight, for example, they show how children on a seesaw can be introduced to the idea of levers. It is a question of the teacher asking the simple questions how a heavy child can balance a light one--and the explanation given by the teacher and confirmed experimentally by the students. A concept is being taught which can be applied to opening doors, lifting objects with our muscles, using a wedge to split wood--once the concept is understood, its applications are obvious--specifically in a tug of war, each child must get his body close to the ground by lowering his center of mass to obtain maximum pulling force. Chapter nine of the same reference concerns Newton's laws--the concept of inertia is particularly relevant in football--both in starting and stopping the ball, and stopping and starting the players--but it can be exemplified in many other ways also. They go on to talk about factors affecting the human body--mass, force and work as we move about, and how these can be incorporated in learning activities The association of ideas--work as force times distance, the effects of friction, air resistance, water resistance in swimming--can all be introduced at a very early age. It is merely the way in which a child thinks about these things which differs--a stimulation of the inate curiosity in all of us.



$$m_1 g/\tan\theta_1 + m_2 g/\tan\theta_2 + m_3 g/\tan\theta_3 = F$$
$$= m_4 g/\tan\theta_4 + m_5 g/\tan\theta_5 + m_5 g/\tan\theta_6$$

TUG OF WAR

Experiment T5.01 Reaction - The Rocket and Balloon

Materials: - aluminum foil - match, paper clip

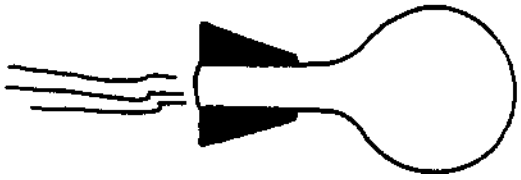
Procedure:

Wrap aluminum foil around upper half of paper match. Push straight pin up under foil to head of match and remove again, leaving an exhaust channel. Place match on opened paper clip and hold lighted match to tip. Step back. The foil must cover the whole of the match head in one piece, and not be punctured. Two or three match heads may be incorporated - after all, two heads are better than one. A most unpleasant odour is given off - better do it outside.

S. J. Tweedie and F. D. Woodruff, Falls Church, Virginia.

Taken from: - The Great International Paper Airplane Book by Mander, Dippel and Gossage, Simon and Schuster- New York.

An alternative is to blow up a balloon and release it. It flies off in all directions, but a suitable tail of cardboard can insure it flies straight.



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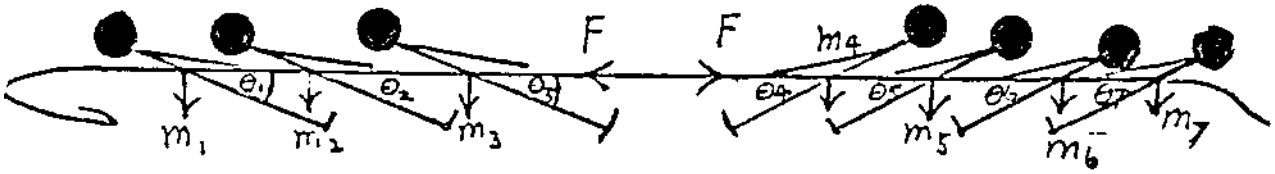

$m_1 g/\tan\theta_1 + m_2 g/\tan\theta_2 + m_3 g/\tan\theta_3 = F$

$= m_4 g/\tan\theta_4 + m_5 g/\tan\theta_5 + m_5 g/\tan\theta_6$

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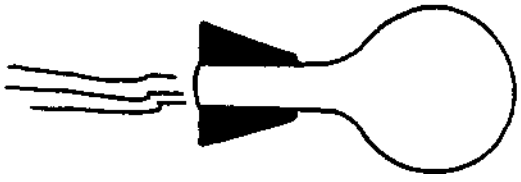
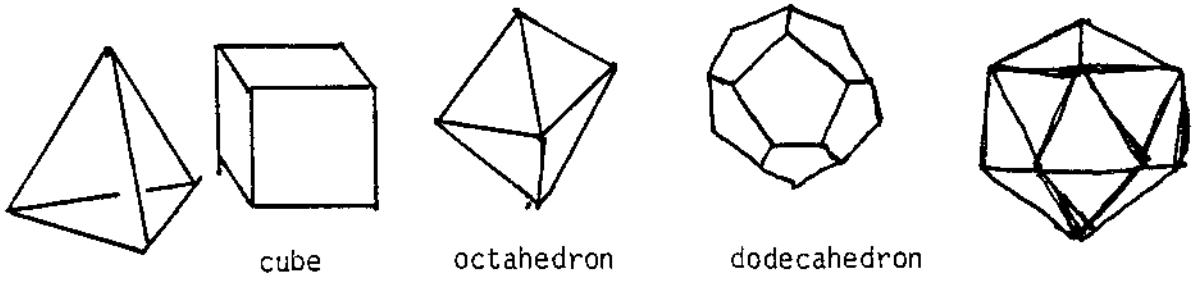


Experiment 15.02 The Platonic Solids

Materials: Straws, paper clips

Procedure: The regular solids of Plato are interesting to construct. The five solids are shown below.

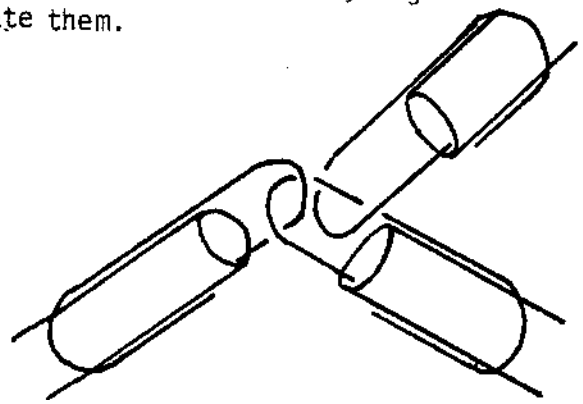


tetrahedron cube octahedron dodecahedron icosahedron

Three of the five can be constructed very easily using straws and #1 paper clips. To construct the tetrahedron, loop three paper clips together, as shown.

Now, stick the small end of each clip into a straw, so you have the ends of three straws attached together. Insert three more such looped sets of clips into the other open ends, and make up triangles by joining pieces of these sets together. In this way you will build a tetrahedron. If you loop four clips together for each corner, you will make an octahedron, and five makes an icosahedron, which has twenty sides. Six gives only a flat plane of triangles--so in a sense, it is a solid with an infinite number of sides. The cube and the pentagonal dodecahedron cannot be built in this way, since the figures are not freestanding.

Count the number of sides, edges and corners of these figures, and try to relate them.



if V = number of vertices
E = number of edges
F = number of faces

Check that

$V - E + F = 2$

Experiment 15.03 - A string and sticky tape digital computer

Although today every student has a digital calculator, how many know what goes on inside? Perhaps they are afraid to find out! In the following experiment you will learn how to build a digital computer which will (at least until you understand it) beat you at the ancient Chinese game of NIM. One of the very first digital computers in England was displayed at the Festival of Britain in 1951 - and it played NIM with all comers. The computer we are building plays NIM to near perfection - but unfortunately, that is all it can do - however, in the process it will inform you, pleasantly, exactly how digital computers work. Glue or tape figure 1 to a piece of card 8½" x 11" (such as the back of a writing pad). This is the baseboard of the computer. Cut two-inch pieces of drinking straw to fit over C, D, E, F and G and a longer piece over H, and tape them down where shown. Now we must make the "flip flops". Two of these are required. Cut a piece of straw 2½ inches long and another 1 inch. Take a piece of tape about 4 inches long, lay the longer piece of straw across it, and tape the shorter piece to the center, as shown in figure 2. Put another piece of tape around the shorter piece as shown to ensure the first piece sticks. Pierce the baseboard from the front with thumbtacks at the points I, J, K, L, M, N, O remove them and push them through the holes from the reverse side so that they stick out from the front. The two flip flops must be pushed over K and M as shown. Now, take them off and enlarge the pivot hole with a pencil point - the flip flop must move very easily. Cut a straw 5" long to act as the indicator Q. It is pivoted at O to move from "computer to "player" and back. Score the line RS and fold the baseboard up by 90° along this line. Stick pieces of tape to hold it at 90° at each end, as shown. The marbles will be held here so as not to run off the table. Score also TU, and fold down 90° - this forms the

stand for the computer and is inclined so the marbles run downhill and work the flip flops. Your computer is now complete. Put 15 marbles into a cup and you are ready to beat the computer. Here is what you do.

1) Set the flip flops as shown in the figure.

2) The rules of the game are, that you may take one, two or three marbles. It is then the turn of the computer, who may also take one, two or three marbles - then back to you. The one who leaves the other player to take the last marble is the winner.

Set the pointer to player. Place the number of marbles you select, one at a time at "INPUT". The first marble moves the first flip flop so its vertical arm moves to the right. The second marble moves it back and goes on to the second flip flop. When you have made your selection, move the point to "computer" and continue to put in marbles until the pointer moves back from "computer" to "player". Now it is your turn again. If you give no thought to how many marbles you choose, you will almost certainly lose. A student playing the game for the first time wonders whether the computer can "think" - you will probably answer no - but then, neither does the largest computer "think" in the way that you or I do. You have constructed a true binary computer, for the "flip flops" you have built can count up to two each, so together they count to four - and this is all they can do. Each "flip flop" has two stable states - and each time a marble drops onto it, it changes from one side to the other - a logic element.

You have constructed a device which

1) Has two logic elements,
2) Is a computer which makes logical decisions based on what state the logic element is in - so they must be set correctly, the computer taking its turn.
3) The computer changes the state of its logic elements as the game progresses.

4) The computer "remembers" the state of the game between moves - i.e. it has a memory.

5) The computer can direct the marbles in the correct channels to win the game.

6) The computer is "programmed" by positioning the elements at the beginning of the game.

Counting, logical functions, altering the internal states and memory are all typical of a computer, and they combine to give the appearance of playing an intelligent game - i.e. if the computer were hidden, you would be unable to decide whether it was an intelligent person or a machine playing.

"Digital" refers here to the logic elements having only two stable positions which are commonly designated "0" and "1" - we could say 0 was to the left, and 1 to the right - the two states for each element make this a binary system.

We could write a flow chart for the computer as in Fig. 3 for each marble. Let us see how this works in a special case starting with 15 marbles. If the flip flop has it's center pillar to the left, we put a bar over it, as $\bar{A}$, if to right, it is A. We set the flip flops to start so the first flip flop A points left, $\bar{A}$ and the second flip flop B points right. This is the essential ingredient if the computer is to win. Let us play a simulated game - we play first and take one marble. The computer than takes 1 marble - and moves to pointer to player. Fig. 3 shows the flip flop orientation.

stand for the computer and is inclined so the marbles run downhill and work the flip flops. Your computer is now complete. Put 15 marbles into a cup and you are ready to beat the computer. Here is what you do.

1) Set the flip flops as shown in the figure.

2) The rules of the game are, that you may take one, two or three marbles. It is then the turn of the computer, who may also take one, two or three marbles - then back to you. The one who leaves the other player to take the last marble is the winner.

Set the pointer to player. Place the number of marbles you select, one at a time at "INPUT". The first marble moves the first flip flop so its vertical arm moves to the right. The second marble moves it back and goes on to the second flip flop. When you have made your selection, move the point to "computer" and continue to put in marbles until the pointer moves back from "computer" to "player". Now it is your turn again. If you give no thought to how many marbles you choose, you will almost certainly lose. A student playing the game for the first time wonders whether the computer can "think" - you will probably answer no - but then, neither does the largest computer "think" in the way that you or I do. You have constructed a true binary computer, for the "flip flops" you have built can count up to two each, so together they count to four - and this is all they can do. Each "flip flop" has two stable states - and each time a marble drops onto it, it changes from one side to the other - a logic element.

You have constructed a device which

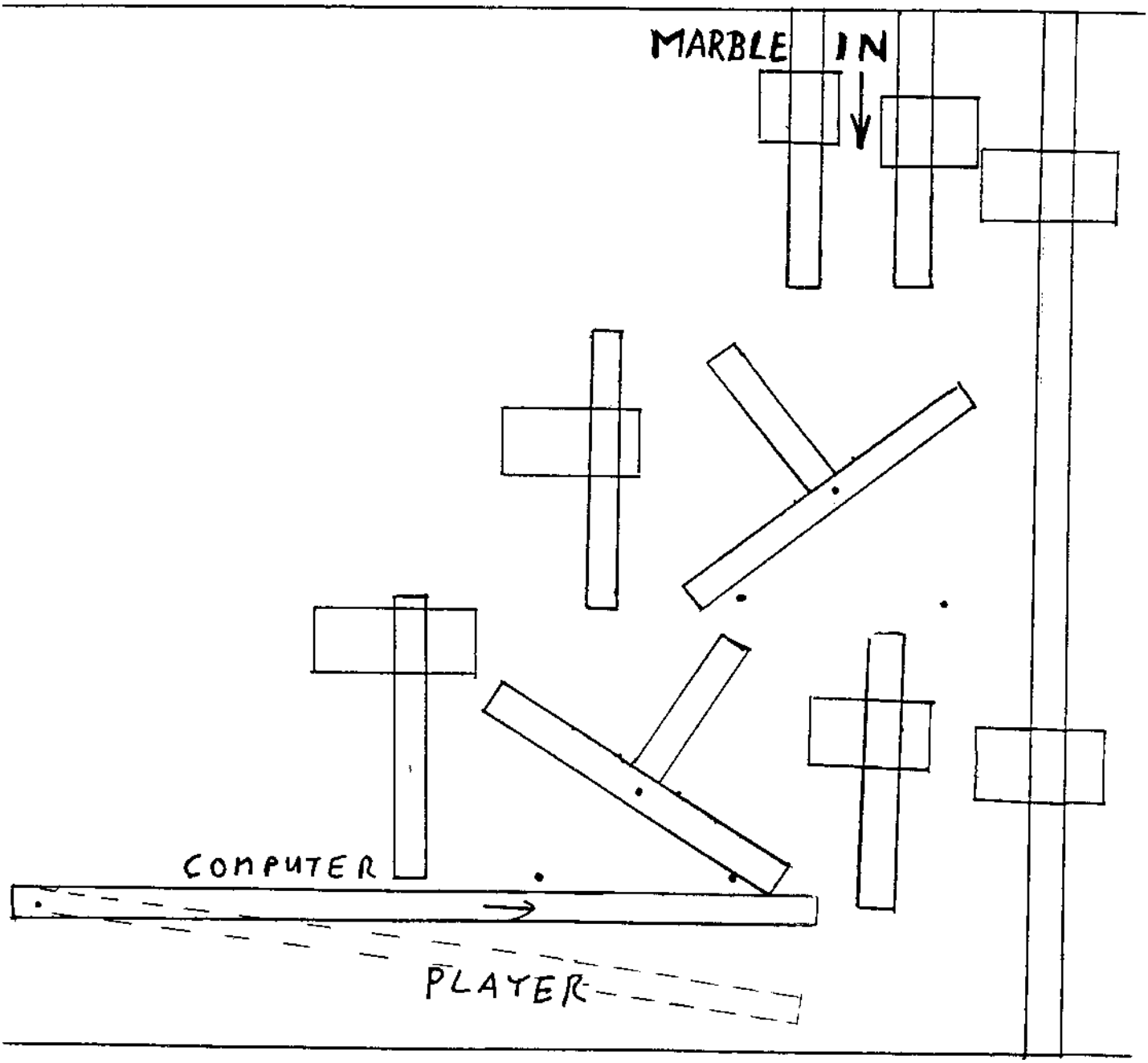
1) Has two logic elements,
2) Is a computer which makes logical decisions based on what state the logic element is in - so they must be set correctly, the computer taking its turn.
3) The computer changes the state of its logic elements as the game progresses.

	Marble Number			
player	1.	$\bar{A}$	B	The first marble flips $\bar{A}$ to A, but does not affect B
	2.	A	B	The next marble flip A, and goes on to flip B
	Pointer Moves			
Player takes 2	3.	$\bar{A}$	$\bar{B}$	
	4.	A	$\bar{B}$	Note A flips each time, but B only every other time
	5.	$\bar{A}$	B	The flip flops return to their original position
computer	6.	A	B	
	pointer moves			
	7.	$\bar{A}$	$\bar{B}$	
player	8.	A	$\bar{B}$	
	9.	$\bar{A}$	B	
computer	10.	A	B	
	pointer moves			
	11.	$\bar{A}$	$\bar{B}$	
player	12.	A	$\bar{B}$	
	13.	$\bar{A}$	B	
computer	14.	A	B	
	pointer moves			
	15.	$\bar{A}$	B	

We Lose!

This type of calculation is called Boolean algebra, which is the basis of all digital computer operation, whether a string and sticky tape device, or the largest fastest computer. We stopped the computer (i.e. switched from the computer to player) because the pointer shifted when the first flip flop moved to $\bar{A}$ and the second $\bar{B}$. In Boolean algebra this would be written

STOP = $[\bar{A}\cdot\bar{B}]$. - i.e. the computer stops when the states are $\bar{A}$ and $\bar{B}$ at the same time. All the basic operations of a digital computer, then, can be carried out by our string and sticky tape computer.


MARBLE IN
COMPUTER
PLAYER

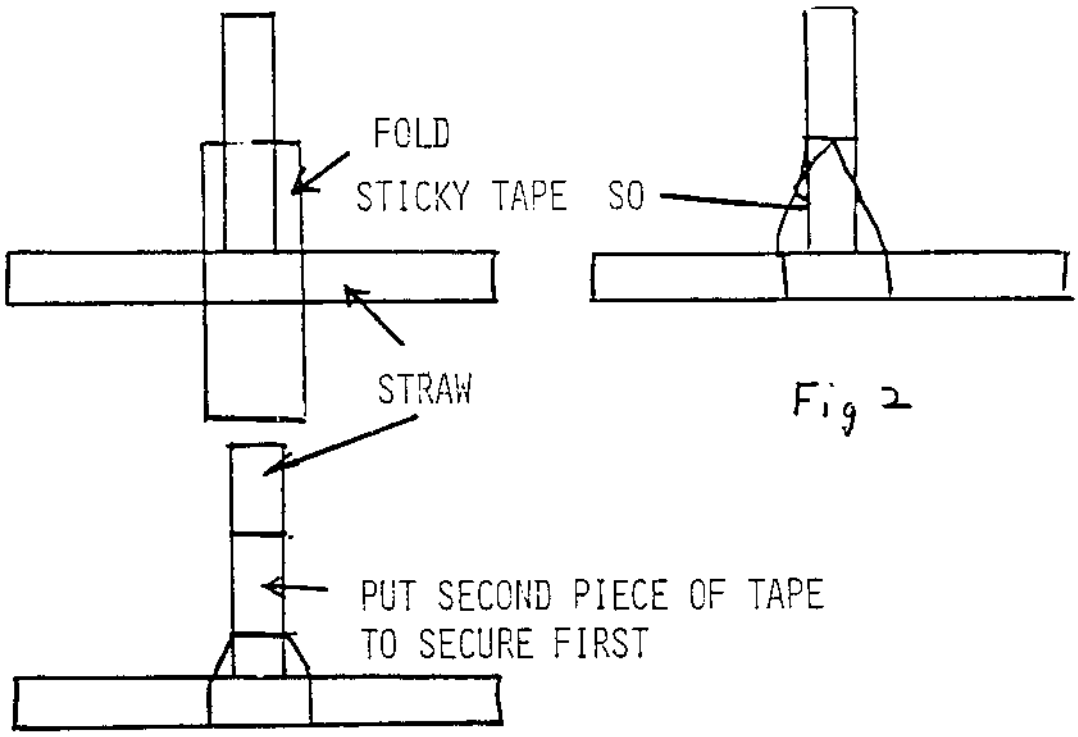
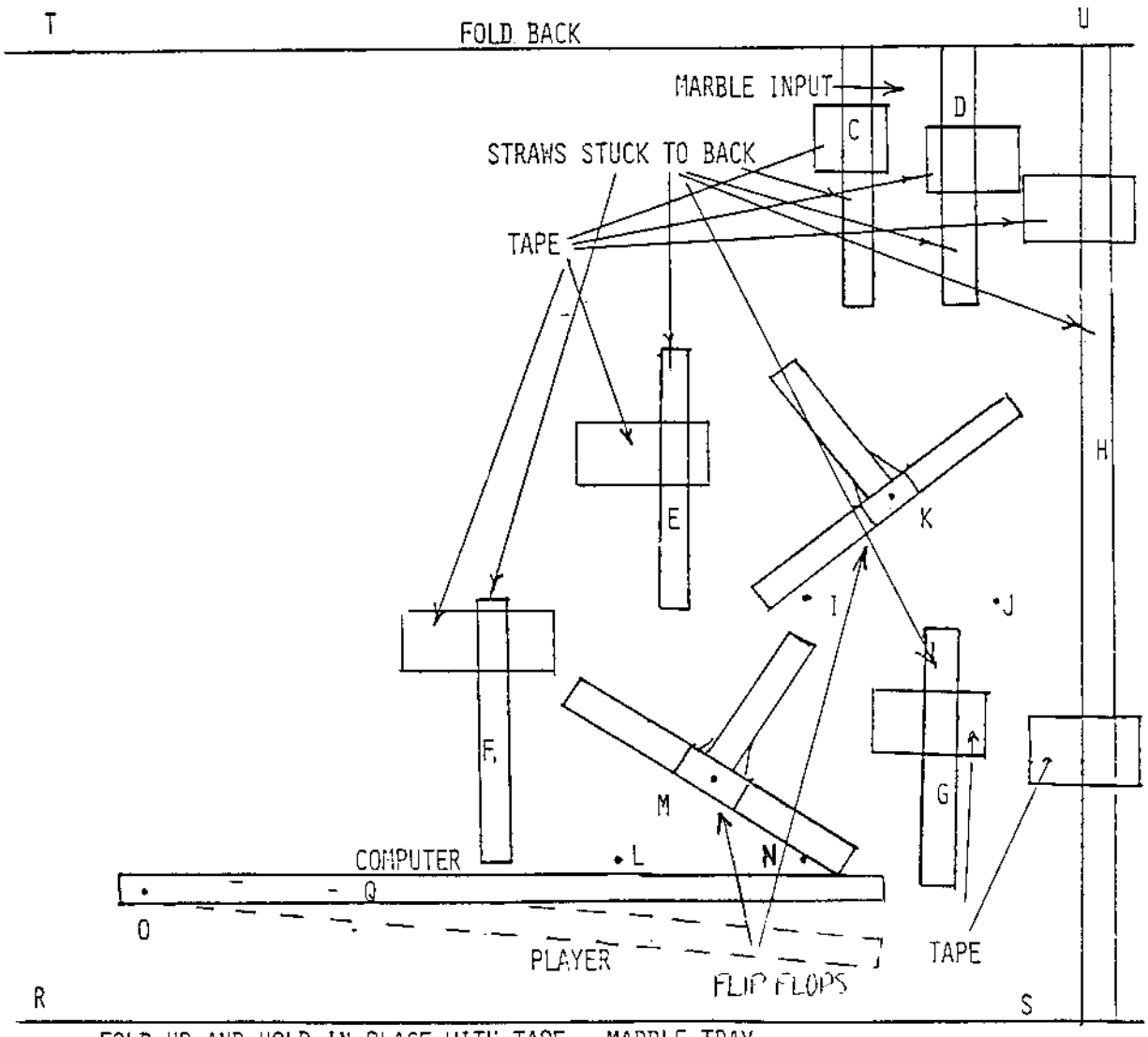
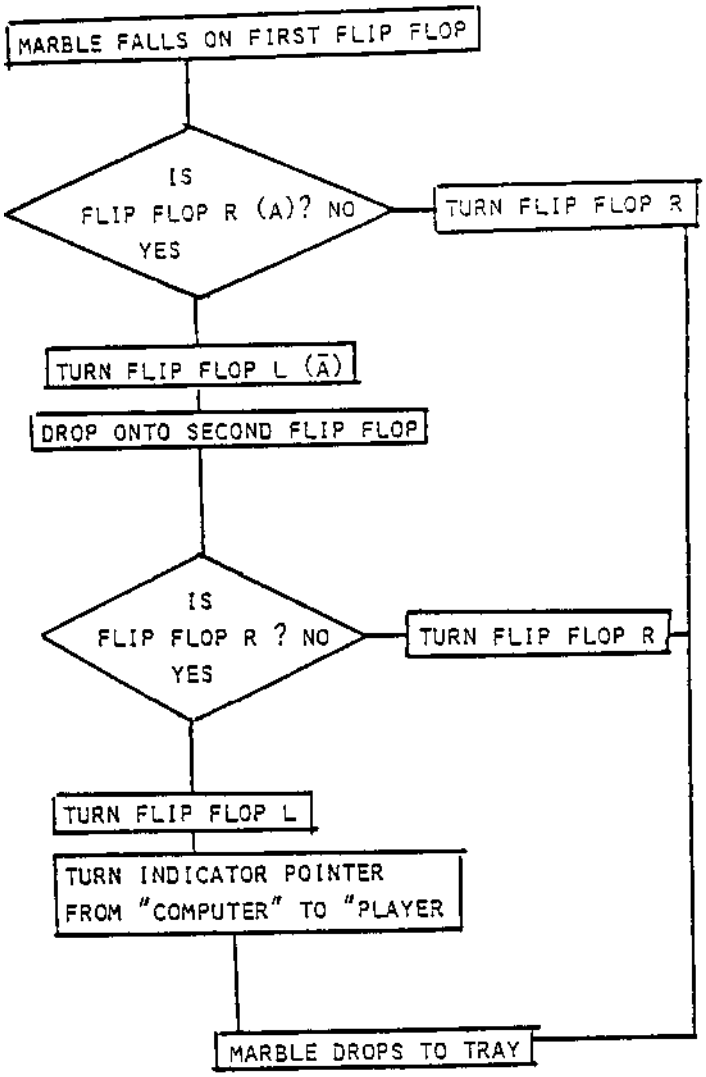


Fig 2



FOLD UP AND HOLD IN PLACE WITH TAPE - MARBLE TRAY


MARBLE FALLS ON FIRST FLIP FLOP
IS FLIP FLOP R (A)? NO
YES
TURN FLIP FLOP R
TURN FLIP FLOP L (Ā)
DROP ONTO SECOND FLIP FLOP
IS FLIP FLOP R ? NO
YES
TURN FLIP FLOP R
TURN FLIP FLOP L
TURN INDICATOR POINTER FROM "COMPUTER" TO "PLAYER
MARBLE DROPS TO TRAY

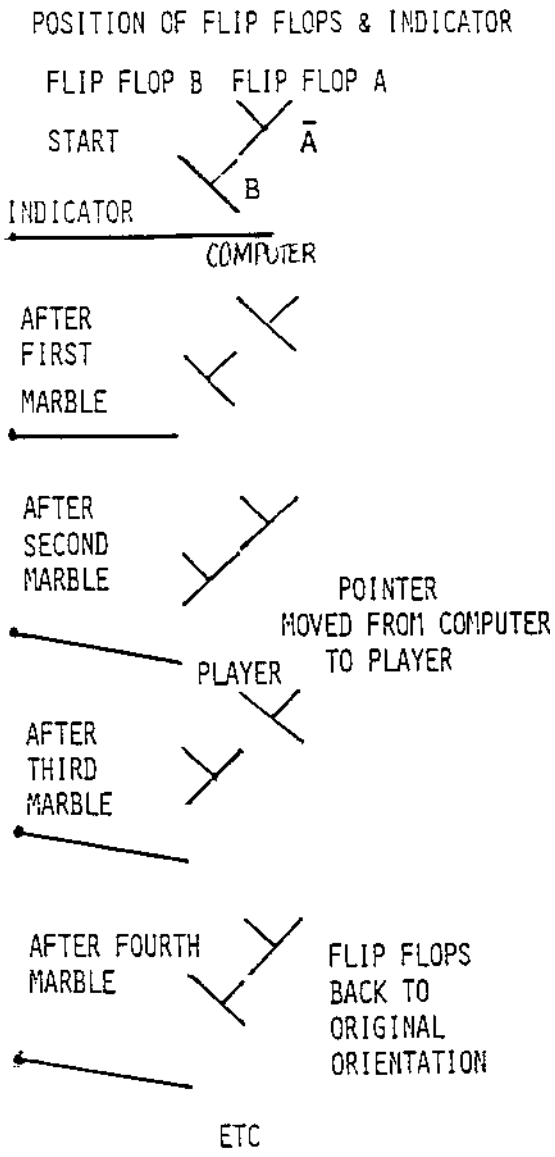

POSITION OF FLIP FLOPS & INDICATOR
FLIP FLOP B
FLIP FLOP A
START
Ā
B
INDICATOR
COMPUTER
AFTER FIRST MARBLE
AFTER SECOND MARBLE
POINTER MOVED FROM COMPUTER TO PLAYER
PLAYER
AFTER THIRD MARBLE
AFTER FOURTH MARBLE
FLIP FLOPS BACK TO ORIGINAL ORIENTATION
ETC

Fig 3

Experiment 15.04 - Four Dimensional Tic-Tac-Toe

It is often difficult to explain the meaning of four-dimensional space to students. Here, as elsewhere, "understanding" four dimensions means using it. The simple game of tic-tac-toe seems to be ideally suited to demonstrating this. We start with the conventional delineation whown in the left top of Figure 1. Each player alternately puts down an X or O, respectively, trying to obtain a line of X's or O's. The extension of this game to three dimensions is straightforward--we have three boards laid out as shown in Figure 1, and imagine them superimposed on top of one another. Examples of winnning straight lines on the cube of three boards is shown. To extend to four dimensions we need nine boards as shown in Figure 2. One can no longer imagine them piled on top of one another, but again, a winning straight line is fairly obvious--several examples given by numbers are shown.

Tic-tac-toe may be extended to have four spaces in each dimension. Such a game in two dimensons proves useful in discussing finite, but not bounded surfaces. In Figure 3, we imagine the left hand edge of the board attached to the right hand side of the board, forming a cylinder as shown. It is possible to play on such a cylindrical board, which only has a top and bottom but no sides. We can now attach the top of the board to the bottom, so that the board has no edges at all. It is not really possible to visualize this, but it is easy to use it. a situation for such a board is shown in Figure 4, where we extend the board beyond the overlap on all edges. A sequence of four X's and O's can continue across what was an edge of the board, as shown. A surface such as this is obviously finite, but has no boundary, which is also a property of a sphere. Note in the specific example shown, we actually have a continuous straight line of X's, much as a great circle on a sphere is a line with no end.

This can be extended to three dimensions, and proves handy in discussing finite, but not bounded, three dimensional game with four spaces is available as "Qubic" manufactured by Parker Brothers.

This game proves quite useful in helping students think in three dimensions, which is very necessary in X-ray crystallography and other subjects where one must visualize molecular and crystal structure.

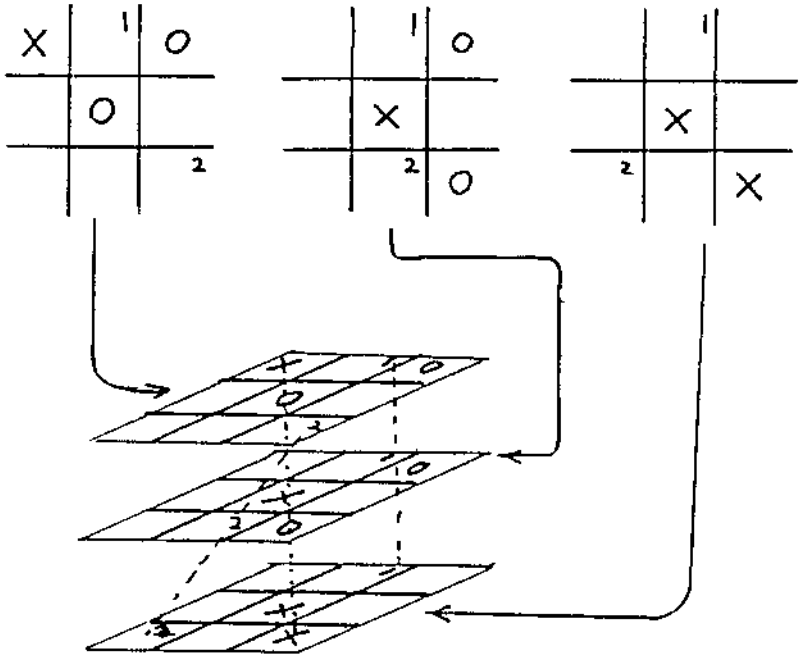


Fig 1.

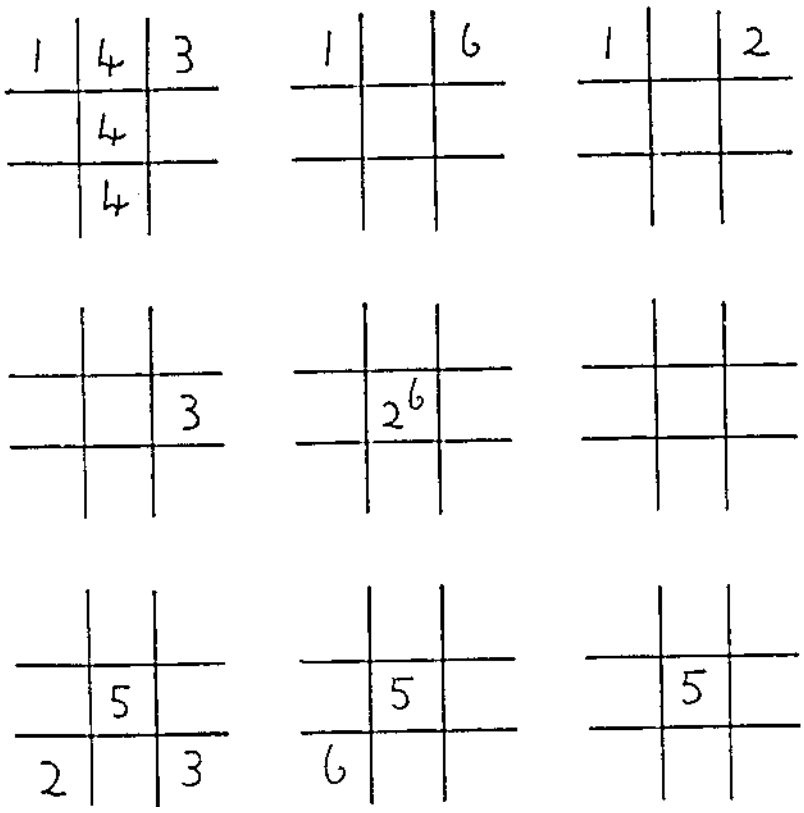


Fig 2

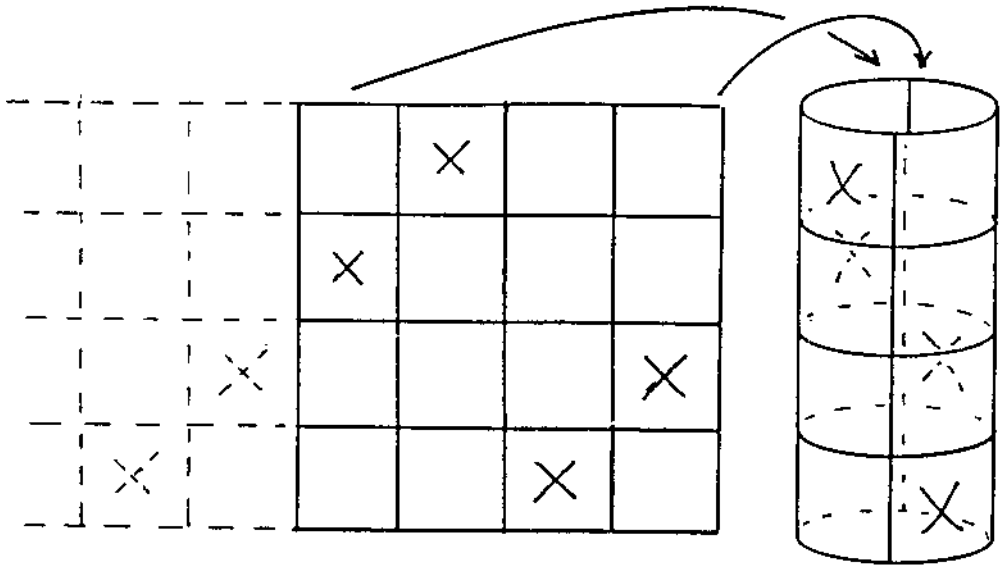


Fig 3

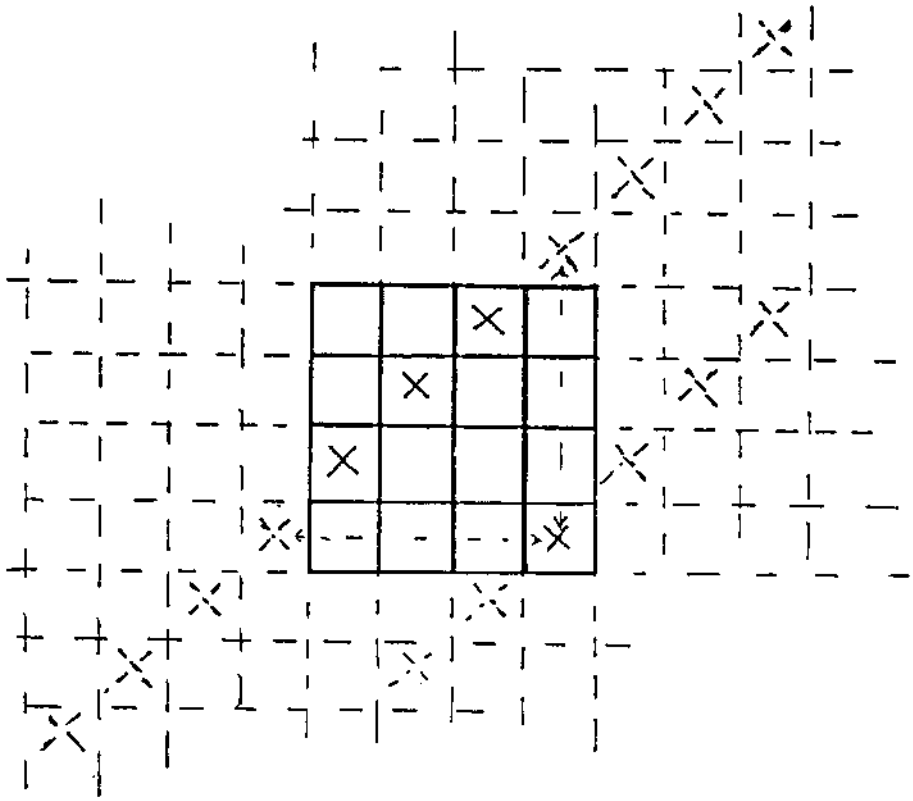


Fig 4

Experiment 15.05 - Simple Vacuum Experiments

We have seen how string and sticky tape may be employed to investigate mechanics, sound, optics, even heat - but what about vacuum experiments? At first sight, it would seem one would need an expensive vacuum pump, a bell jar, yards and yards of vacuum tubing, and so forth. However, there are quite a few experiments one can do simply using preserve jars, such as Mason or Ball jars. These are designed to withstand the vacuum used in canning, and the high temperatures involved in this process. The larger jars (32 oz.) are most useful - but a little dangerous.

Basically, we place a little water in the jar with the lid loosely attached. The water boils, steam fills the jar, escaping and completely displacing the air. We carefully screw the top on, holding the jar with a towel in order not to get burned. In fact, the jars are mostly self sealing, so that as they cool down the vacuum holds the top on with a force of 1.01×10^5 N/m^2 or Pascals (32 lb/sq in) multiplied by the area of the top (diameter 6.5 cm giving about .0033 m^2, or 5 sq in). This is a force of 333 N (165 lb. wt.). It follows, take great care of the evacuated jar - an implosion caused by dropping it could be dangerous. The pressure due to water vapor inside the jar at room temperature (30°C) is 32 mm Hg (4,252 Pa, .042 atm). If you put the jar in the freezer, it will fall to 4 mm Hg, (532 Pa .0052 atm) which is quite a good enough vacuum for most experiments, and, furthermore, the water will freeze on the bottom of the jar, so it will not run when the jar is shaken or moved.

What kind of experiments can be performed? The favorite is generally showing that sound will not travel through a vacuum. It would be convenient to glue a hook (a paper clip) to the lid, but unfortunately the boiling water generally prevents this holding, so a support, such as shown in fig. 1, can

be bent out of a wire clothes hanger. A small bell, a bunch of keys, or anything which will jingle, is attached by a short length of string or thread to the support. A rubber band support is better, but tends to get destroyed by the boiling water. The object is to provide no path for the sound to escape via the support. Shake the jar, and convince yourself that you can hear the objects jingling. Now, evacuate the jar and repeat the process. Can you hear the keys? Pry the lid off a little to allow some air in. How much air is required before the keys become audible? In letting the air in, notice how much force is required to remove the top - 333 N (or 165 lb. wt.)

A second experiment shows how a balloon expands in a vacuum. A rubber balloon may be used, but it tends to deteriorate in boiling water. Sealable polyethylene sandwich bags work quite well, provided they are sealed quite tight. Put the bag, or balloon with just a little air in, in the jar. Boil the water and seal the jar - the balloon or bag will rapidly swell to fill the whole jar. Now let the air in slowly and note how the bag collapses.

The next experiment is to show air has weight. We need a small, sensitive balance. Poke about three holes through a soda straw, as shown, the middle one a little above the others. Support a small plastic bottle (one the heat will not warp) or piece of styrofoam from one end, using a paper clip, and attach enough paper clips to the other end just so they outweigh the ball. Put the balance in the jar, as shown, and evacuate. Whereas previously the bottle or foam was buoyed up by the atmosphere, in the jar the vacuum does not do this, and the mass of air inside the object will cause it to outweigh the clip - or, more accurately, there is no longer air being displaced by it so it weighs more heavily. This is not an easy experiment - it requires quite a lot of adjustment to get the balance just right - and the support must be reasonably free - tapping

the jar helps here. The next experiment should be done immediately after removing the jar from the stove and screwing the top on. Pour cold water (ice water is best) on the top. The water inside will immediately start boiling again. Water condenses on the cold top, and because the pressure is now below equilibrium for the hot water, it boils. If one inverts the jar and puts it on ice, the water will freeze on the lid, because the freezing point of ice at low pressure is just a little less than at room temperature. (Remember the pressure of ice skates melt the ice under them? This is just the opposite.) Unfortunately, one atmosphere only raises the freezing point .007°C, so you may have difficulty with this one. A little salt on the ice will cover the freezing point so the water inside the jar freezes. Furthermore, at these low pressures, the water drops on the walls will rapidly evaporate and condense on the lid.

Another experiment is a variation of the "guinea and feather tube". Unfortunately, the feather will stick to the wall, because of the surface tension of the water in the jar. However, if you make up a little object such as that shown in fig. 3 out of thin plastic, the object will not stick because the edges and not the sides touch the walls of the jar. Put a penny and this object in the jar and note they both fall rapidly on turning the jar upside down. In air, the plastic object falls slowly. Shake the jar, and note the object moves from one end of the jar to the other because of its inertia. It will not do this if the jar is full of air.

One of the simplest and most spectacular vacuum experiments is to take an empty soft drink can, boil a little water in it until steam is emitted vigorously, then rapidly invert the can and plunge it, open end downward, in a basin of cold water. The steam immediately condenses and collapses the can.

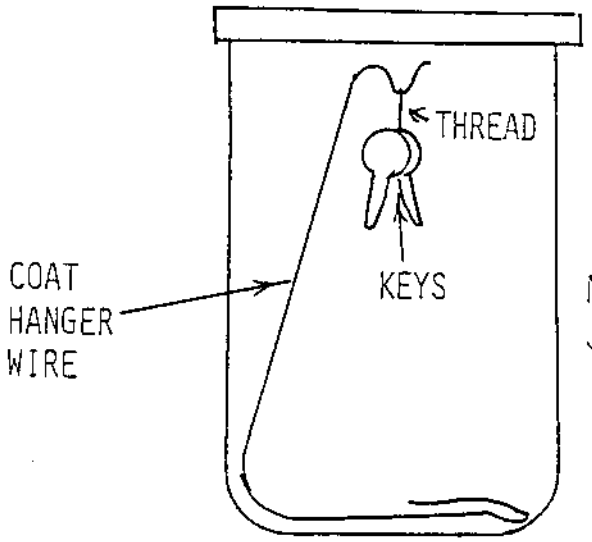


FIG 1

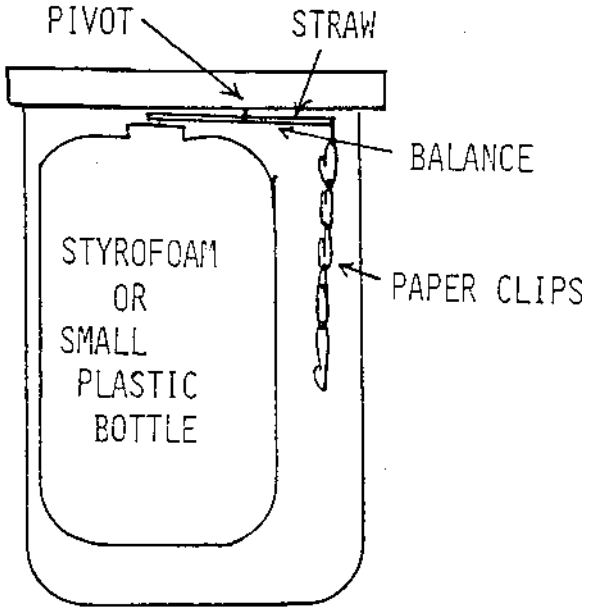


FIG 2

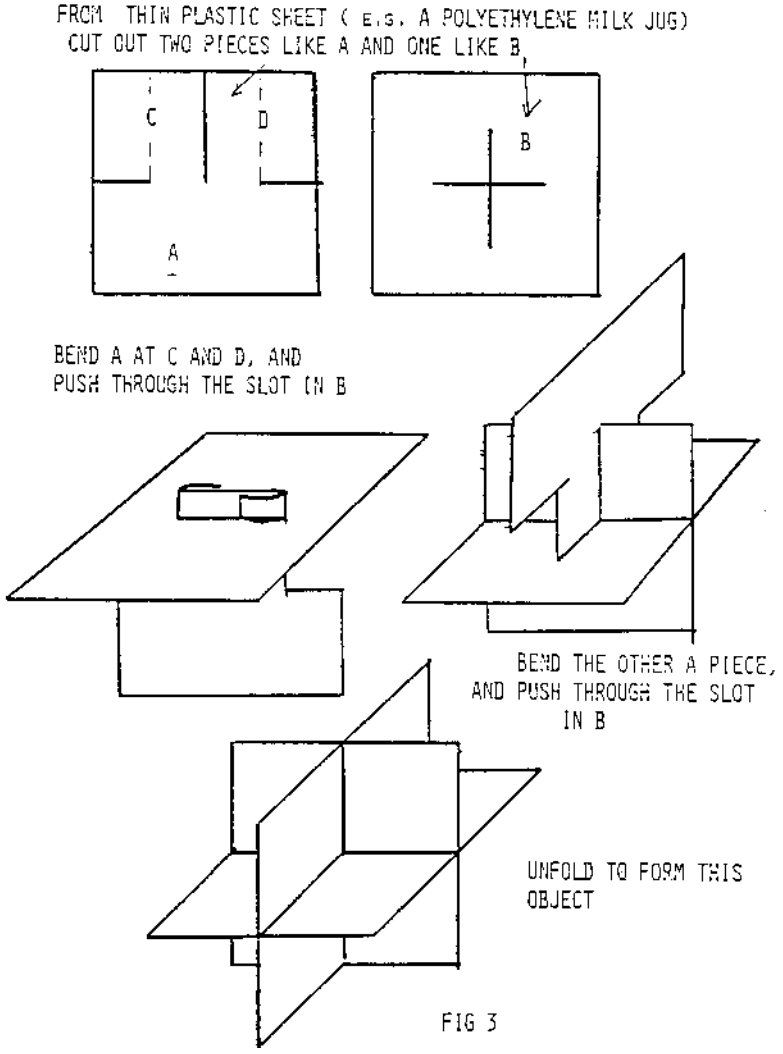

FROM THIN PLASTIC SHEET (E.G. A POLYETHYLENE MILK JUG)
CUT OUT TWO PIECES LIKE A AND ONE LIKE B
C
D
A
B
BEND A AT C AND D, AND
PUSH THROUGH THE SLOT IN B
BEND THE OTHER A PIECE,
AND PUSH THROUGH THE SLOT
IN B
UNFOLD TO FORM THIS
OBJECT

FIG 3